Challenges for Adopting and Implementing IoT in Smart Cities: An Integrated MICMAC-ISM approach

Marijn Janssen
Faculty of Technology, Policy & Management, Delft University of Technology
The Netherlands
Email: M.F.W.H.A.Janssen@tudelft.nl

Sunil Luthra
State Institute of Engineering & Technology, Nilokheri, Haryana, India
Email: sunilluthra1977@gmail.com

Sachin K. Mangla
Plymouth Business School
University of Plymouth, UK
Email: Sachin.kumar@plymouth.ac.uk

Nripendra P. Rana*
Emerging Market Research Centre (EMaRC)
School of Management
Swansea University, Fabian Way, Swansea, SA1 8EN, UK
Email: nrananp@gmail.com

Yogesh K. Dwivedi
Emerging Market Research Centre (EMaRC)
School of Management
Swansea University, Fabian Way, Swansea, SA1 8EN, UK
Email: y.k.dwivedi@swansea.ac.uk

Abstract

Purpose – The wider use of Internet of Things (IoT) makes it possible to create smart cities. The purpose of this research is to identify key IoT challenges and understand the relationship between these challenges to support the development of smart cities.
Design/methodology/approach – Challenges were identified using literature review, and prioritised and elaborated by experts. The contextual interactions between the identified challenges and their importance were determined using Interpretive Structural Modelling (ISM). To interrelate the identified challenges and promote IoT in the context of smart cities, the dynamics of interactions of these challenges were analysed using an integrated Matrice d'Impacts Croisés Multiplication Appliqués à un Classement (MICMAC)-ISM approach. MICMAC is a structured approach to categorise variables according to their driving power and dependence.
Findings – Security and privacy, business models, data quality, scalability, complexity and governance were found to have strong driving power and so are key challenges to be addressed in sustainable cities projects. The main driving challenges are complexity and lack of IoT governance. IoT adoption and implementation should therefore focus on breaking down complexity in manageable parts, supported by a governance structure.

Practical implications – This research can help smart city developers in addressing challenges in a phase-wise approach by first ensuring solid foundations and thereafter developing other aspects.

Originality/value – A contribution originates from the integrated MICMAC-ISM approach. ISM is a technique used to identify contextual relationships among definite elements, whereas MICMAC facilitates the classification of challenges based on their driving and dependence power. The other contribution originates from creating an overview of challenges and theorising the contextual relationships and dependencies among the challenges.

Keywords: Internet of Things; Smart Cities; Interpretive Structural Modelling; ISM; MICMAC; Challenges

Paper type: Research paper

1. Introduction

Today, 54% of the world's population live in urban areas – a proportion that is expected to increase to 60% by 2030 (The United Nations Report, 2012; De Jong et al., 2015). As a result, the concept of smart cities has become more and more relevant worldwide over the past few years as a model to address issues, such as the increasing global human population, environmental and green challenges and the increased role of information system technology in society (Obaidat, 2015).

Information and Communication Technology (ICT) is increasingly viewed as a tool for creating sustainable smart cities (Albino et al., 2015; Zhuhadar et al., 2017). Among others, Hui et al. (2017) emphasised the need to use IoT to create sustainable smart cities. The Internet of Things (IoT) is expected to drive the transformation of many existing industrial systems such as transportation, energy and manufacturing systems (Xu et al., 2014). Connected IoT devices are part of the key elements of a smart city and their use is becoming increasingly common in daily life. IoT can be used to decrease energy use of households and companies (Shrouf and Miragliotta, 2015), reduce energy consumption and pollution of traffic (Neirotti et al., 2014), track and trace goods (Barrero et al., 2010; Luo et al., 2016) and promote more sustainable consumption and production (Vergragt et al., 2016; Xu et al., 2018b). IoT uses the Internet grounded information design, which allows the exchange of data, information and services connected in a network (Li et al., 2016a).

Currently, there is a shift from not only generating data to extracting useful information from the data (Ray and Verma, 2016). The expectation is that there will be approximately 50 billion linked objects by 2020 (Evans, 2011). With the rapid deployment of networked infrastructure and wide usage of smart IoT devices, smart cities are becoming a new paradigm of city life (Ianuale et al., 2015; Xu et al., 2018b). Smart cities are advancing towards an instrumented, integrated, and intelligent living space, where IoT, mobile technologies and next generation networks are expected to play a key role (Piro et al., 2014; Li et al., 2016b). In smart cities, numerous IoT-based services are likely to be available and a key challenge is to allow mobile users perform their daily tasks dynamically, by integrating the services available in their vicinity (Urbieta et al., 2017). Despite its promises, IoT is still evolving and facing many challenges (Arasteh et al., 2016; Mehmood et al., 2017; Li et al., 2018). There is growing awareness of potential problems and challenges associated with the development of IoT-based smart cities (Lenz, 2014). Challenges include technology, standardisation, security, and privacy (Xu et al., 2014) and the development of viable business models (Li et al., 2018). All these challenges hinder the use of IoT to create smart cities (Stojkoska and Trivodaliev, 2017; Zhuhadar et al., 2017; Cheng et al., 2018). Although for developing smart cities, a variety of IoT-related challenges should be overcome, there is no structured overview of the main categories of challenges encountered by smart cities. Furthermore, there is no theorising about the relationship between challenges in the literature to understand how they depend on each other and what their significance is. To address the void in the literature, the following research questions are formulated:

> RQ1: What are the main categories of challenges for adopting and implementing IoT in smart cities?
>
> RQ2: What are the relationships between the challenges?
>
> RQ3: Which challenges should be undertaken first for smart city development?

Given the lack of research on the development of IoT-based smart cities in emerging economies like India, this study is motivated to set the following research objectives to answer above mentioned research questions:

i To identify the key challenges in development of IoT-based smart cities,
ii To evaluate the interrelationships between identified challenges and cluster them by using a driving power-dependence graph, and
iii To develop a hierarchical structural model of identified challenges to efficiently adopting and implementing IoT in smart cities.

The aim of the research presented in this paper is to identify these challenges and understand the relationship between them. An Integrated Matrice d'Impacts Croisés Multiplication Appliqués à un Classement (MICMAC)-Interpretive Structural Modelling (ISM) approach is used, as this approach is suitable to (e.g. Luthra and Haleem, 2015): (i) discover relationships between the challenges; (ii) classify challenges per their driving-dependence power; and (iii) develop a hierarchical structural model among the challenges. The later can help governments and smart cities developers in determining which challenges should be addressed first.

This article is structured as follows: a review of related literature is presented in the next section followed by the research approach in Section 3. MICMAC analysis and ISM results are presented in Section 4. Section 5 discusses the research findings and Section 6 provides implications for theory and practice. Conclusions, limitations and future research suggestions are provided in Section 7.

2. Literature Review

This section contains the literature on IoT and its role in smart city, and identification of major challenges for adopting and implementing IoT in smart cities to highlight a theoretical lens that underpins the study.

2.1 IoT and its role in smart city

The concept of IoT dates back almost a century and came from Nicolas Tesla who, in a 1926 interview, spoke about wireless communication. The term was coined by Professor K. Ashton in 1999 during a presentation he made at Procter & Gamble (Ashton, 2009), but it is only recently that IoT – the interconnection of physical devices with embedded sensing and communication possibilities – is used in the context of smart cities. The definition of ‘smart city’ is cantered on the use of network infrastructures to improve general efficiency and allow economic and political development in social, cultural and urban regards (Ianuale et al., 2015).

A smart city is a complex ecosystem characterised by the intensive use of ICT aiming at making the cities more attractive, more sustainable and a unique place for innovation and entrepreneurship. The major stakeholders include application developers, service providers, citizens, government and public service providers, research community, platform developers, etc. (Mehmood et al., 2017).

IoT will affect the various aspects of the smart city citizens’ life like health, security, and transportation. On the other hand, it can play an important role at the national level regarding to the policy decisions (like energy saving, pollution decrement, etc.), remote monitoring and required infrastructure, etc. (Arasteh et al., 2016). But, besides the advantages, IoT is still evolving and facing many challenges. Therefore, next subsection identifies the key challenges in development of IoT-based smart cities.

2.2 Challenges for IoT-based in Smart Cities Development

Literature was reviewed to identify challenges associated with the development of smart cities using IoT. Keywords used for data collection included ‘Internet of Things’, ‘Smart Cities’ and ‘Challenges’, and combinations of these keywords, including ‘Internet of Things and Smart Cities’, ‘Internet of Things and Challenges’, ‘Smart Cities and Challenges’ and ‘Internet of Things and Smart Cities and Challenges’. Next, in order to collect research articles, we made the use of several search engines including Google Scholar, Scopus and Google, and various databases such as Science Direct, ISI WoS, Emerald, Scopus, Taylor & Francis, DOAJ, EBSCO, Wiley and Inderscience. This resulted in the identification of 54 relevant papers from various journals (e.g. Ad Hoc Networks, Computer Communications, Computer Law & Security Review, Internet Research, Computer Networks, Future Generation Computer Systems, Information Systems Frontiers, Journal of Network and Computer Applications) and conference proceedings (e.g. Hawaii International Conference on System Sciences, IEEE International Conferences and Springer Conferences) to reports (e.g. the European Commission Report and the United Nations Report). Articles were selected based on their relevance in terms of the role of IoT in developing smart cities. Sixteen key challenges were identified as shown in Table 1.

Table 1: Overview of challenges from literature for the development of IoT based smart cities

S. No.	IoT challenges	Implied Meaning	Sources
1.	Security and privacy issues	IoT collects potentially private or sensitive data which can be for used by a variety of parties. Therefore, secure information sharing, and data protection is needed. Large numbers of IoT devices are often vulnerable to attacks and end-to-end security is not easy to create in a complex network of stakeholders.	Weber, 2010; Gubbi et al., 2013; Oman et al., 2013; Li et al., 2014; Li et al., 2016a; Li and Xu, 2017
2.	Lack of interoperability	Interoperability is needed as data from drivers and heterogeneous devices need to be combined. Lack of interoperability hinders or blocks the development of applications.	Borgia, 2014; Perera et al., 2014; Díaz et al., 2016; Zhang et al., 2017; Gürdür and Asplund, 2018
3.	Legal issues	Data collection and sharing should not violate legislation and policies and be in compliance with data protection and security acts.	Perera et al., 2014; Ahlmeyer and Chircu, 2016
4.	Lack of IoT governance and management support	Data ownership, processing and use are often done in different phases. It is often unclear that who controls the system and what responsibilities each party has.	Weber, 2009; Ahlmeyer and Chircu, 2016; Weber and Studer, 2016; Bennett et al., 2017
5.	Ethical and societal issues	The diffusion of IoT poses major ethical and societal challenges such as the misuse of information for other purposes, revealing personal identity, lack of fairness and social justice.	Sundmaeker et al., 2010; Weber, 2013; Weber and Studer, 2016

6.	Costing issues	The creation of networks of sensors, screens, cameras, smart devices, smart grid and a secure information-sharing infrastructure requires significant investment and collaboration between parties, and the benefits may not always be divided equally.	Gubbi et al., 2013; Zanella et al., 2014
7.	Mobility-related problems	Mobile devices move from one place to another (with their owners or cars) and need connectivity to transmit the generated data. IoT networks need to be able to deal with the variety in connection problems and the resulting data latency (delay).	Gubbi et al., 2013; Borgia, 2014; Mineraud et al., 2016; Fernández-Ares et al., 2017
8.	Complexity problems	A large number of devices differ in life cycle length, reliability and are operated by many actors result in a complex landscape.	Khan et al., 2012; Sta, 2017
9.	Lack of reliability and robustness (system failures)	The reliability of systems has been reported as a problematic issue in designing smart houses. IoT needs a huge amount of location-based sensory data and should be robust enough to ensure its effectiveness.	Chan et al., 2008; Zhang et al., 2016
10.	Lack of resources	This is important to manage the many resources (equipment, humans, systems) required for performing the intended functions in developing an efficient IoT-driven smart city. An identification mechanism needs to be in place that can uniquely identify each and every sensor and object in the framework.	Barnaghi et al., 2012; Parry et al., 2016; Patra and Rao, 2016
11.	Issues related to data quality and scalability	The accurateness, timeliness and completeness of obtained data can differ. The quality of data is influenced by many factors e.g., sensing equipment, process parameters and variables and data transmitting and receiving system.	Barnaghi et al., 2012; Borgia, 2014
12.	Lack of expertise and knowledge	There might be a lack of skills and expertise. In particular governments have difficulties in attracting technical professionals.	Gade et al., 2016; Yu et al., 2016; Pierce and Andersson, 2017
13.	Stakeholder engagement and collaboration issues	The majority of smart city initiatives lack collaboration, cooperation and coordination by different private and public actors due to varying interests.	Miorandi et al., 2012; Pierce and Andersson, 2017
14.	Technological problems	IoT is still developing and devices differ in quality. In addition, to gain any benefits, modern technologies like cloud computing, machine learning, data analysis techniques and intelligent sensors are needed.	Jun et al., 2011; Borgia, 2014; Li et al., 2015; Li et al., 2016b; Luo et al., 2016; Bennett et al., 2017; Zhang et al., 2017
15.	Public awareness and acceptance issues	There is still a resistance to new and unknown technologies. Public trust and social acceptance are crucial for the successful development of IoT-based smart cities. Lack a trust could potentially cause the whole model or system to fail.	Sheng et al., 2013; Perera et al., 2014
16.	Standardisation and network flexibility issues	There are no uniform standards for IoT systems and data collection, causing low network flexibility. Replacing old devices and adding new devices could prove very complicated. Government should develop and unify the technical standards for IoT devices.	Miorandi et al., 2012; Weber, 2013; Pascual et al., 2014; Weber and Studer, 2016; Xu et al., 2016; Vuletic et al., 2017; Xu et al., 2018a

[Legend: IoT: Internet of Things, S.No.: Serial Number]

Nowadays, cities have become smarter by going digital: they deploy digital equipment that is utilised by various applications (e.g. street cameras and sensors) (Kyriazis et al., 2013). Our list of literature-derived challenges shows that many of the challenges are multi-faceted and interrelated and range from the organisational to the technical level. Although this list provides insight into the types of challenges, it does not reveal their interrelationships and significance, and decisions will need to be made as to the appropriate order in which the challenges should be tackled.

3. Research Approach

The aim of this research is to identify key IoT challenges and understand the relationship between these challenges to understand which of them should be considered when developing smart cities. Using literature review, 16 key challenges were identified. Next, experts were asked to evaluate the challenges. This result in removing one challenge, whereas two new challenges were added, the details are provided in Subsection 4.2.1.

The contextual interactions between the finalised 17 key challenges and their importance were determined using ISM – a structural modelling technique to establish hierarchical relationships within a set of elements (Kumar et al., 2016). Interpretive approaches help in understanding the system dynamics by knowing the interactions among the variables, which are influencing and influenced by other variables (Xu, 2000; Achi et al., 2016).

Challenges are related to each other and the integrated MICMAC-ISM based model was developed to understand the relationships between the challenges. MICMAC is a structured approach to categorise variables according to their driving power and dependence. A driving power-dependence categorises variables into four categories: autonomous, dependent, linkage and independent (Mangla et al., 2013).

ISM is a technique used to identify contextual relationships among definite elements (Warfield, 1974). It is a combination of three modelling languages – words, digraphs, and discrete mathematics – to offer a better methodology for structuring complex issues (Luthra et al., 2015; Kumar et al., 2016) over AHP and DEMATEL techniques (Sindhu et al., 2016; Luthra et al., 2017). MICMAC facilitates the classification of challenges based on their driving and dependence power, which is not only useful in proving the significance of certain variables, but also results in exposing certain elements due to their influence on others (Mangla et al., 2013).

The integrated MICMAC-ISM analysis consists of several steps (Haleem et al., 2016), which are explained below in relation to the objective of this work:

Step 1: Identify and finalise the variables in relation to the research problem. IoT challenges in developing smart cities were identified through literature survey and discussions with experts.

Step 2: Develop a questionnaire and collect data to form contextual relationships between listed IoT challenges in developing smart cities through survey instrument. Establish pairwise relations between identified challenges to develop Structural Self-Interaction Matrix (SSIM).

Step 3: Establish Initial Reachability Matrix (IRM) with the help of the SSIM matrix. Test the initial reachability matrix for transitivity, make modifications to satisfy the transitivity requirements and derive the Final Reachability Matrix (FRM). Derive the driving and dependence power of each challenge by summation of entries in rows and columns in FRM.

Step 4: Classify the FRM into various levels to develop an ISM structural hierarchy of listed IoT challenges. Obtain reachability set and antecedent set from the reachability matrix to determine various levels. In the reachability set, we clustered the challenge itself and the other challenges affected by that challenge. In the antecedent set, we combined the challenge to other challenges affecting the challenge. After finding the reachability set and antecedent set, the intersection for these sets was derived (intersection set).

Step 5: Develop a MICMAC analysis graph of identified challenges. The objective of the MICMAC analysis is to analyse the driving power and the dependence of the variables. According to the driving and dependence power of the challenges, we classified the challenges into four different categories (autonomous, dependent, linkage, and independent).

Step 6: Develop the ISM-based hierarchy of challenges with the help of the FRM and final levels of the challenges. An ISM-based model is used to represent the visual representation of the challenges and their interdependence.

The flow chart of the integrated MICMAC-ISM method used for this work is shown in Figure 1.

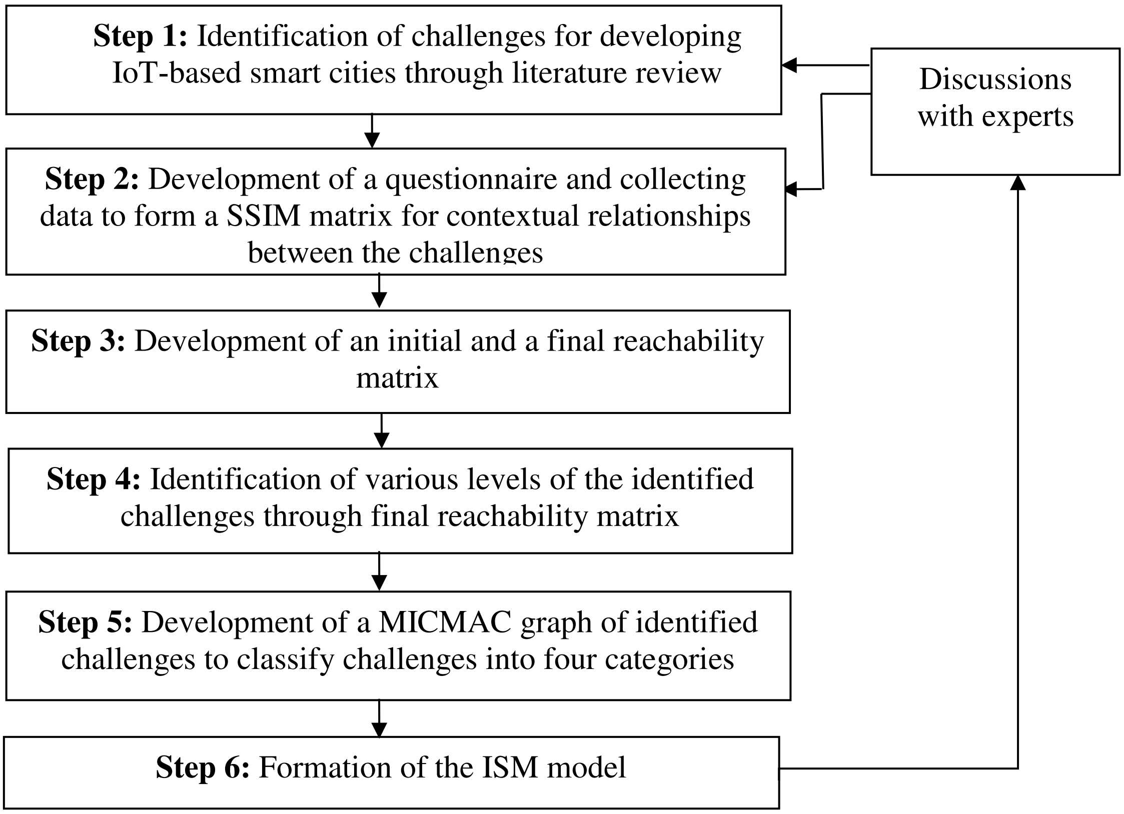

Figure 1: Flowchart of the main research steps

4. Data Analysis and Results of MICMAC-ISM

This section discusses data collection and analysis. The related results of an integrated MICMAC-ISM approach have been provided in further subsection.

4.1 Question development and data collection

To collect data, a data collection instrument, as shown in Annexure I, was developed. This questionnaire consists of three sections. Section A aims to collect general information about the respondents and the industries they belong to. Section B focuses on selecting the most suitable challenges and explores their relevance to IoT in developing smart cities. Section C examines the contextual interactions between the selected challenges. The number of suitable experts in the field of IoT and smart cities was found to be small. Although many technical experts and public servants with knowledge of possible applications and associated challenges were involved in the development of smart cities, most of them lacked the knowledge to answer the survey questions on the specific challenges that we identified. By contacting smart city project managers and using our own network through LinkedIn and snowballing as our main search strategy, we found seven experts with sufficient expertise to answer the questions.

All experts were involved in IoT smart cities projects, had knowledge of both the organisational and technical challenges with expertise and skills in this field (individual profiles) with a minimum of 10 years of relevant work experience. The sample size taken for this work is sufficient and properly representative of the population under investigation. The demographic summary of experts is presented through Table 2.

Table 2: Demographic information on experts

Category	**Classification**	**Number of Experts**
Job Profile/Department	Academics	2
	Ministry of Infrastructure and the Environment	1
	Municipalities	2
	Smart Cities project managers	1
	Traffic and mobility department	1
Education	Bachelor’s degree	1
	Master’s degree	2
	PhD	4
	Other	Nil
Work experience	Under 5 years	Nil
	5-10 years	Nil
	10-15 years	4
	15-20 years	1
	More than 20 years	2
Size of organisation	Fewer than 50 employees	Nil
	50-250 employees	Nil
	250-500– employees	1
	500-1000 employees	1
	1000-5000 employees	3
	More than 5000 employees	2
Sector classification	Private Sector	1
	Public Sector	5
	Multinational corporation	Nil
	Regulatory body	1
	Mixed public and private ownership	Nil

4.2 Proposed research application and related results

MICMAC analysis integrated with ISM approach has been used to establish major challenges to IoT in developing of smart cities. The results of each step are described below.

4.2.1 Step 1: Identify and finalise the challenges to IoT-based smart cities

16 challenges that were derived from the literature review were taken as a starting point for the further analysis. To determine the importance of the identified challenges, a feedback survey was mailed to experts to gather input. The significance was measured using a five-point Likert scale (with 1 indicating ‘not significant at all’ and 5 indicating ‘very significant’). Prior to conducting the survey, we agreed that challenges with a mean score of less than 3 would be omitted, and challenges with a mean score of 3 or higher would be considered as meaningful.

After recording the responses, one challenge with a mean score of 2.57, namely ‘Mobility problems’, was omitted from the initial list of the challenges.

Respondents were also asked if there were any key IoT challenges, which were not listed in the initial list. As a result, two challenges i.e. ‘Poor government vision’ and ‘Lack of business model innovations/solutions’ were added to the list. Again, the recorded responses were sent to the experts for a second round of feedback and to obtain their consensus on the two new challenges. Cronbach’s alpha (CA) values for all the challenges were found above the suggested threshold value of 0.70 (Nunnaly, 1978; Hair et al., 1992). The collected data was then analysed. The descriptive statistics of IoT challenges in developing smart cities is shown in Table 3.

Table 3: The descriptive statistics of IoT in developing smart cities

S. No.	**IoT challenges for smart cities**	**Experts’ score**							**Mean**	**Standard Deviation**	**Standard Error**	**Cronbach's Alpha**
		1	**2**	**3**	**4**	**5**	**6**	**7**				
1	Security and privacy issues	5	4	5	5	5	5	4	4.71	0.488	0.184	0.858
2	Lack of interoperability	4	4	4	3	5	4	4	4.00	0.577	0.218	0.857
3	Legal issues	4	5	4	5	5	4	4	4.43	0.535	0.202	0.857
4	Lack of IoT governance and management support	5	5	5	5	5	5	4	4.86	0.378	0.143	0.857
5	Ethical and societal issues	5	5	5	4	5	4	4	4.57	0.535	0.202	0.857
6	Costing issues	4	5	4	3	3	5	5	4.14	0.900	0.340	0.857
7	Mobility problems	1	3	2	2	3	3	4	2.57	0.976	0.368	0.858
8	Complexity problems	3	5	4	5	4	5	5	4.43	0.787	0.297	0.858
9	Lack of reliability and robustness (system failures)	3	4	4	4	5	4	4	4.00	0.577	0.218	0.857
10	Lack of resources	3	4	3	3	3	3	5	3.43	0787	0.297	0.858
11	Issues related to data quality and scalability	4	3	3	3	4	3	3	3.29	0.787	0.297	0.858
12	Lack of expertise and knowledge	3	3	3	3	2	4	3	3.00	0.577	0.218	0.857
13	Stakeholder engagement and collaboration issues	5	4	4	4	4	5	5	4.42	0.535	0.202	0.857
14	Technological problems	3	2	3	3	4	4	4	3.29	0.756	0.286	0.857
15	Public awareness and acceptance issues	3	5	4	3	5	3	3	3.71	0.951	0.360	0.857
16	Standardisation and network flexibility issues	4	4	3	3	4	5	4	3.86	0.690	0.261	0.857
17	Poor government vision	4	5	5	5	5	4	4	4.57	0.535	0.202	0.857
18	Lack of business model innovations/solutions	4	5	4	4	5	5	4	4.29	0.535	0.202	0.857

Finally, consensus was obtained in the experts’ responses. In total, 17 key challenges related to the development of IoT-based smart cities were selected for inclusion in the next steps.

4.2.2 *Step 2: Develop Structural Self-Interaction Matrix (SSIM)*

Once the challenges were finalised, a contextual relationship of ‘leads to’ was used to analyse the factors. The ‘leads to’ contextual relationships mean that one factor influences another factor. Based on the experts’ responses, an SSIM matrix was constructed showing the contextual relationships (see Table 4). For indicating the direction of interaction between the challenges (say, i and j), four symbols were used as shown below.

V-Challenge i will influence challenge j;

A-Challenge j will influence challenge i;

X-Challenges i and j will influence each other, and

O-Challenges i and j are not related to each other

Table 4: SSIM for IoT-based challenges in developing smart cities

Element P(i)	IoT challenges	Contextual Relationships															
		17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
C1	Security and privacy issues	V	O	V	V	O	V	V	V	V	V	A	X	V	A	V	O
C2	Lack of interoperability	A	A	V	A	O	O	A	O	A	X	A	O	O	O	O	
C3	Legal issues	V	O	V	X	V	O	O	A	O	O	A	A	X	A		
C4	Lack of IoT governance and management support	V	O	V	V	V	V	O	V	O	V	X	V	V			
C5	Ethical and societal issues	O	X	V	X	O	V	O	O	V	V	A	O				
C6	Costing issues	V	V	V	O	O	V	V	X	O	V	A					
C7	Complexity problems	V	V	O	V	O	O	V	O	V	O						
C8	Lack of reliability and robustness	O	A	V	A	A	A	A	O	A							
C9	Lack of resources	X	A	V	A	X	X	X	O								
C10	Issues related to data quality and scalability	O	O	V	V	O	V	O									
C11	Lack of expertise and knowledge	X	A	V	A	X	X										
C12	Stakeholder engagement and collaboration issues	X	A	V	A	X											
C13	Technological problems	X	A	V	O												
C14	Public awareness and acceptance issues	V	X	V													
C15	Standardisation and network flexibility issues	O	A														
C16	Poor government vision	V															
C17	Lack of business model innovations/solutions																

4.2.3 *Step 3: Initial Reachability Matrix and Final Reachability Matrix*

In this step, the SSIM is transformed into a binary matrix known as the Initial Reachability

Matrix (IRM) by replacing V, A, X, and O symbols by binary digits (1 and 0). Several rules were followed to frame the IRM for the challenges of IoT-based smart city development (see Table 5). These rules are described below:

The IRM contains 1 for (i, j) and 0 for (j, i) for corresponding V in the SSIM;

The IRM contains 0 for (i, j) and 1 for (j, i) for corresponding A in the SSIM;

The IRM contains 1 for (i, j) and 1 for (j, i) for corresponding X in the SSIM;

The IRM contains 0 for (i, j) and 0 for (j, i) for corresponding O in the SSIM.

Table 5: Initial reachability matrix for IoT-based challenges in developing smart cities

Challenge	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**	**C17**
C1	1	0	1	0	1	1	0	1	1	1	1	1	0	1	1	0	1
C2	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
C3	0	0	1	0	1	0	0	0	0	0	0	0	1	1	1	0	1
C4	1	0	1	1	1	1	1	1	0	1	0	1	1	1	1	0	1
C5	0	0	1	0	1	0	0	1	1	0	0	1	0	1	1	1	0
C6	1	0	1	0	0	1	0	1	0	1	1	1	0	0	1	1	1
C7	1	1	1	1	1	1	1	0	1	0	1	0	0	1	0	1	1
C8	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
C9	0	1	0	0	0	0	0	1	1	0	1	1	1	0	1	0	1
C10	0	0	1	0	0	1	0	0	0	1	0	1	0	1	1	0	0
C11	0	1	0	0	0	0	0	1	1	0	1	1	1	0	1	0	1
C12	0	0	0	0	0	0	0	1	1	0	1	1	1	0	1	0	1
C13	0	0	0	0	0	0	0	1	1	0	1	1	1	0	1	0	1
C14	0	1	1	0	1	0	0	1	1	0	1	1	0	1	1	1	1
C15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
C16	0	1	0	0	1	0	0	1	1	0	1	1	1	1	1	1	1
C17	0	1	0	0	0	0	0	0	1	0	1	1	1	0	0	0	1

Next, we constructed the Final Reachability Matrix (FRM) from the IRM by considering transitivity rule as depicted in Table 6 (see Step 2 of methodology for details).

Table 6: Final reachability matrix for IoT-based challenges in developing smart cities

Challenge	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**	**C17**
C1	1	1*	1	0	1	1	0	1	1	1	1	1	1*	1	1	1*	1
C2	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
C3	0	1*	1	0	1	0	0	1*	1*	0	1*	1*	1	1	1	1*	1
C4	1	1*	1	1	1	1	1	1	1*	1	1*	1	1	1	1	1*	1
C5	0	1*	1	0	1	0	0	1	1	0	1*	1	1*	1	1	1	1*
C6	1	1*	1	0	1*	1	0	1	1*	1	1	1	1*	1*	1	1	1
C7	1	1	1	1	1	1	1	1*	1	1*	1	1*	1*	1	1*	1	1
C8	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
C9	0	1	0	0	0	0	0	1	1	0	1	1	1	0	1	0	1
C10	1*	1*	1	0	1*	1	0	1*	1*	1	1*	1	1*	1	1	1*	1*
C11	0	1	0	0	0	0	0	1	1	0	1	1	1	0	1	0	1
C12	0	1*	0	0	0	0	0	1	1	0	1	1	1	0	1	0	1
C13	0	1*	0	0	0	0	0	1	1	0	1	1	1	0	1	0	1
C14	0	1	1	0	1	0	0	1	1	0	1	1	1*	1	1	1	1
C15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
C16	0	1	1*	0	1	0	0	1	1	0	1	1	1	1	1	1	1
C17	0	1	0	0	0	0	0	1*	1	0	1	1	1	0	1*	0	1

*Adding transitivity

4.2.4 Step 4: Partitioning of levels

The reachability set (i.e. R(P_i)) for each single challenge consists of the challenge itself and the other challenges, which it may influence, whereas the antecedent set (i.e. A(P_i)) consists of the challenge itself and the other challenges, which may help in achieving them. The intersection (i.e. R(P_i)∩A(P_i)) of these sets was derived for all challenges. The challenges for which the reachability and the intersection sets are same, occupy the top level in the ISM hierarchy. Table 7 shows all the challenges with their reachability set, antecedent set and the associated levels with performed initial iteration.

Table 7: First iteration process for IoT-based challenges in developing smart cities

Element P(i)	Reachability set R(Pi)	Antecedent set A(Pi)	Intersection set R(Pi)∩A(Pi)	Level
1	1,2,3,5,6,8,9,10,11,12,13,14,15,16,17	1,4,6,7,10	1,6,10	
2	2,8,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17	2,8	
3	2,3,5,8,9,11,12,13,14,15,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
4	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17	4,7	4,7	
5	2,3,5,8,9,11,12,13,14,15,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
6	1,2,3,5,6,8,9,10,11,12,13,14,15,16,17	1,4,6,7,10	1,6,10	
7	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17	4,7	4,7	
8	2,8,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17	2,8	
9	2,8,9,11,12,13,15,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	
10	1,2,3,5,6,8,9,10,11,12,13,14,15,16,17	1,4,6,7,10	1,6,10	
11	2,8,9,11,12,13,15,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	
12	2,8,9,11,12,13,15,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	
13	2,8,9,11,12,13,15,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	
14	2,3,5,8,9,11,12,13,14,15,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
15	15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17	15	1
16	2,3,5,8,9,11,12,13,14,15,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
17	2,8,9,11,12,13,15,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	

Once the top level is identified, the challenge(s) involved in that level is/are removed from further iteration. Then, the same process is repeated for the next level. This process is continued until the level for each challenge is found. In total, six iterations were performed. The results of the iterations can be found in Annexure II. Table 8 shows the final levels for the challenges.

Table 8: Levels for IoT-based challenges in developing smart cities

S. No.	Level	IoT challenges in developing smart cities
1	Level 1	- Standardisation and network flexibility issues (C15)
2	Level 2	- Lack of interoperability (C2) - Lack of reliability and robustness (C8)
3	Level 3	- Lack of resources (C9) - Lack of expertise and knowledge (C11) - Stakeholder engagement and collaboration issues (C12) - Technological problems (C13) - Lack of business model innovations/solutions (C17)
4	Level 4	- Legal issues (C3) - Ethical and societal issues (C5) - Public awareness and acceptance issues (C14) - Poor government vision (C16)
5	Level 5	- Security and privacy issues (C1) - Costing issues (C6) - Issues related to data quality and scalability (C10)
6	Level 6	- Lack of IoT governance and management support (C4) - Complexity problems (C7)

4.2.5 *Step 5: MICMAC analysis*

MICMAC stands for 'Matrice d'Impacts Croisés Multiplication Appliqués à un Classement' (cross impact matrix-multiplication applied to classification) and involves the development of a graph to classify different criteria into four categories, or sets, based on their driving and dependence power – autonomous, linkage, dependent and independent criteria. In order to compute the driving and dependence power of each challenge in the present study, we analysed the FRM and calculated the summation of rows and columns (see Table 6). Thereafter, the MICMAC analysis graph was plotted as shown in Figure 2.

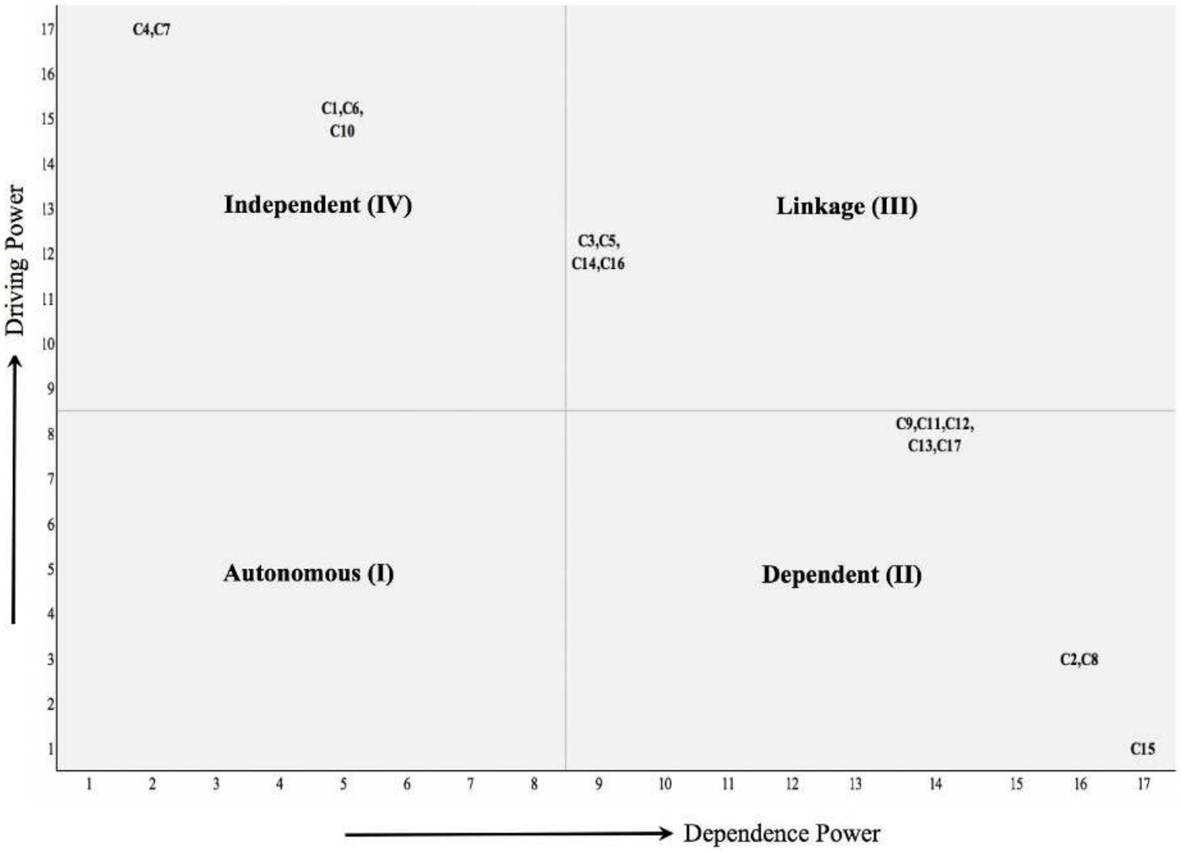

Figure 2: MICMAC analysis for IoT challenges in developing smart cities

This was used as input to develop a graph to categorise all 17 selected challenges into four sets as follows:

1. **Autonomous challenges**: This set of challenges has weak driving and weak dependence power and is relatively disconnected from the system. The non-occurrence of autonomous challenges indicates that all the selected challenges have a significant influence on IoT in relation to the development of smart cities.
2. **Dependent challenges**: This set of challenges has weak driving power but strong dependence and occupies higher importance levels in the developed ISM-based hierarchical model. There are eight challenges belonging to the dependent set: 'Lack of

interoperability (C2)’, ‘Lack of reliability and robustness (C8)’, ‘Lack of resources (C9)’, ‘Lack of expertise and knowledge (C11)’, ‘Stakeholder engagement and collaboration issues (C12)’, ‘Technological problems (C13)’, ‘Standardisation and network flexibility issues (C15)’ and ‘Lack of business model innovations/solutions (C17)’. The strong dependence of these challenges indicates that they need all the other challenges to diminish the effect of these challenges during implementation of IoT. These are significant challenges due to their strong dependence on other challenges. Therefore, practitioners will need to focus on all other challenges not only to achieve the dependent set of challenges but also to manage the adoption of IoT in developing smart cities.

3. **Linkage challenges**: This set of challenges has strong driving as well as dependence power and occupies comparatively lower levels of importance in the ISM-based hierarchical model. In the present study, four challenges belong to the linkage set: ‘Legal issues (C3)’, ‘Ethical and societal issues (C5)’, ‘Public awareness and acceptance issues (C14)’ and ‘Poor government vision (C16)’. Challenges belonging to this category are unstable in the fact that any action on these challenges will have an effect on others and also a feedback effect on themselves. Therefore, these challenges need to be monitored at each stage of the process or should be omitted.
4. **Independent challenges**: This set of challenges has strong driving power but weak dependence power and constitutes the foundation of the ISM-based hierarchical model. In the present study, five challenges belong to this set: ‘Security and privacy issues (C1)’, ‘Lack of IoT governance and management support (C4)’, ‘Costing issues (C6)’, ‘Complexity problems (C7)’ and ‘Issues related to data quality and scalability (C10)’. Practitioners or policymakers must address these driving challenges, or ‘key challenges’, in order to accomplish the desired objectives. Challenges with strong driving power can easily influence other challenges as well. Hence addressing these challenges should be given priority.

4.2.6 Step 6: Development of ISM-based hierarchical model

Based on the FRM (Table 6) and final levels of the challenges (Table 8), the hierarchical structural model of challenges is created. The ISM-based hierarchical model showing the interrelationship between challenges is shown in Figure 3.

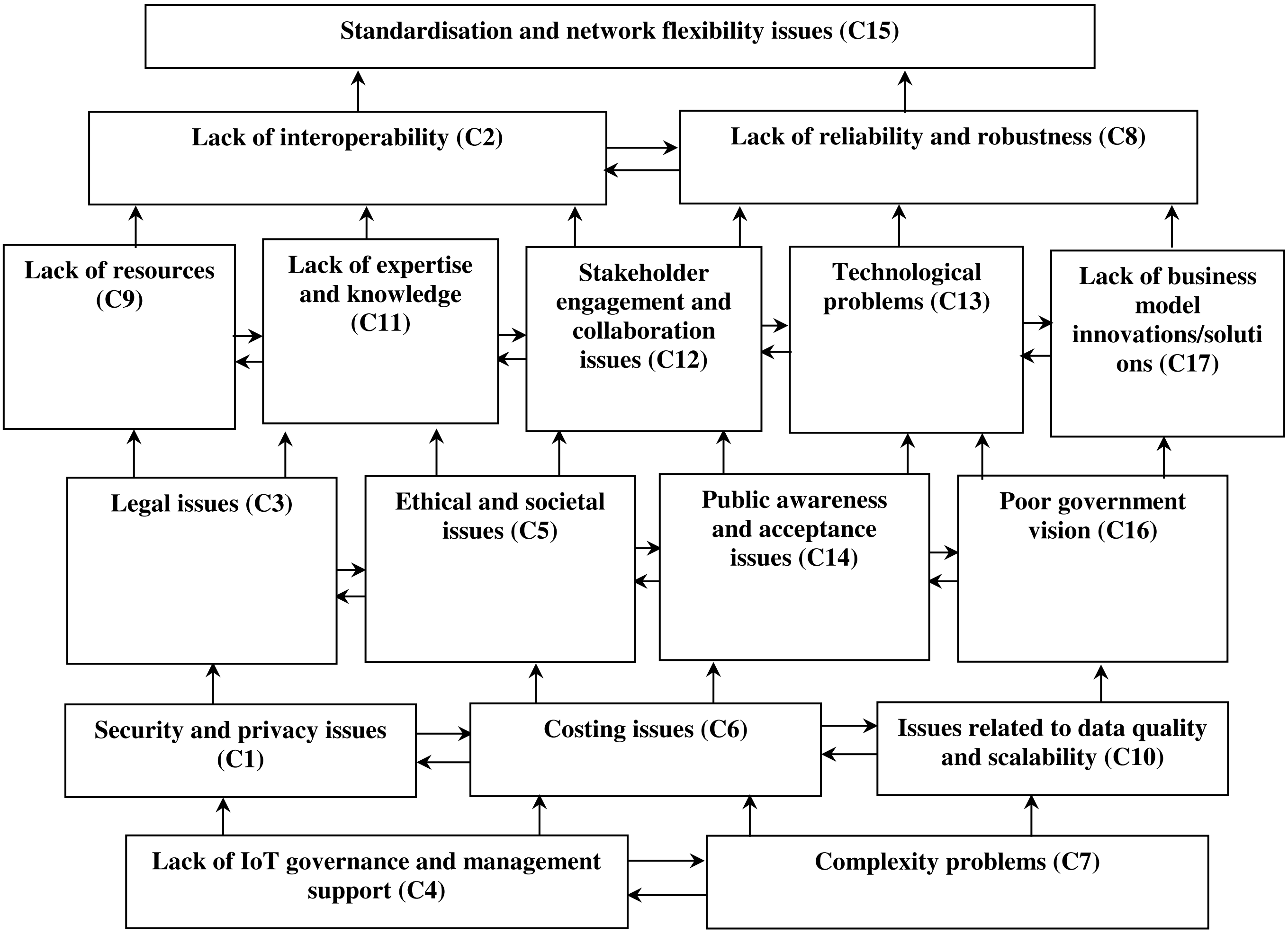

Figure 3: ISM-based hierarchical model for IOT challenges in developing smart cities

5. Discussion

The derived model shows the relationship between the challenges when using IoT to develop smart cities. The non-occurrence of autonomous challenges in this study indicates that all the challenges are interrelated, which adds to the complexity of using IoT in smart cities. A reason for the non-occurrence of autonomous challenges can be found in the focus on critical challenges in this study. There may be other challenges that are less critical.

Independent challenges with strong driving power include 'Lack of IoT governance and management support (C4)' and 'Complexity problems (C7)', which form the foundation of the hierarchical structure depicted in Figure 3.

The complexity and lack of governance in dealing with this complexity is hindering the use of IoT in smart cities. Addressing these challenges should be given priority in adoption and implementation projects. These results confirm the findings of Shin (2017) that the development of IoT carries a tremendous amount of complexity at the individual, organisational, social and national levels. As complexity-related issues make the development of IoT in smart cities challenging, methods need to be employed to decompose complexity. As the findings suggest, these complexity issues can be dealt with by having sound governance mechanisms in place. Governance should be aimed at letting public and private parties collaborate. Such an approach also reflects the findings of Nastic et al. (2015) on the need for governance in large IoT systems.

Next, the challenges ‘Complexity (C4)’ and ‘Governance (C7)’ may lead to ‘Security and privacy issues (C1)’, ‘Costing issues (C6)’ and ‘Issues related to data quality and scalability (C10)’ in adopting IoT in smart cities. These are typical key issues that need to be addressed in order to ensure the success of IoT projects. According to Nath and Som (2017) there are a number of problematic issues with IoT networks, such as privacy, security and confidentiality. A major challenge for policy planners and system representatives is to protect the interconnected devices by having appropriate security mechanisms in place. Despite its importance, the adoption of IoT security measures is lagging (Ahlmeyer and Chircu, 2016). Perera et al. (2014) found in their research that the financial resources for investments in new physical and IoT infrastructure to support smart cities are still limited. The challenges C1, C4 and C6 affect each other bilaterally and are placed at level 5 in ISM model. According to this model, these three challenges lead to ‘Legal issues (C3)’, ‘Ethical and societal issues (C5)’, ‘Public awareness and acceptance issues (C14)’ and ‘Poor government vision (C16)’. Practitioners and policymakers must therefore address these driving challenges to enable the adoption of IoT in smart cities. As challenges with higher driving power can easily influence other challenges, addressing them should be given priority to successfully adopt and implement IoT projects in smart cities. Challenges belonging to this category are unstable because any action related to these challenges will have an impact on the other challenges, and also have an impact on their own, in turn.

Ethical and societal issues, such as individual identity, autonomy of users, fairness, client consent and social justice, also need to be addressed (Weber and Studer, 2016). Public acceptance issues should to be supported by increasing the understanding of inner-workings and the implications of the IoT model in developing smart cities. Challenges C3, C5, C14 and C16 also affect each other bilaterally and are placed at Level 4 in terms of their importance in ISM model.

Next, these four challenges lead to ‘Lack of resources (C9)’, ‘Lack of expertise and knowledge (C11)’, ‘Stakeholder engagement and collaboration issues (C12)’, ‘Technological problems (C13)’ and ‘Lack of business model innovations/solutions (C17)’. These five challenges show the importance of managing the mechanisms or resources (equipment, systems and human resources) required for performing the intended functions in developing an efficient IoT-driven smart city in a timely fashion. IoT in smart cities might be more driven by companies than by governments since companies have the expertise and know-how. The current state of the resources becomes a more challenging issue when scalability, diversity and resource constraints are also considered (Parry et al., 2016). Various stakeholders struggle to assemble their system using a variety of different components, tools and frameworks (Shin, 2017). Sheng et al. (2013) which suggests that there is a considerable need to understand IoT's practical benefits and limitations, and its interdependence with application functions to develop IoT communications on a large scale. In addition to technical concerns, the adaptation of the IoT pattern is impeded due to lack of feasible business models for attracting investments to encourage the applicability and acceptance of modern IT-based technologies (Zanella et al., 2014). The five above-mentioned challenges are equally important and have been placed at level 3 in the ISM model.

The more technical challenges are top-level factors in the ISM model (see Figure 3), indicating the immaturity of the technology and the need for technology maturity before IoT in smart cities can fly. The challenges C9, C11, C12, C13 and C17 further support 'Lack of interoperability (C2)' and 'Lack of reliability and robustness (C8)'. These two challenges are viewed as equally important. IoT networks require low-power solutions (low-power sensors, memory and batteries) and limited network capability and interoperability is needed to exchange and store data (Díaz et al., 2016). The need for robust and reliable IoT solutions to develop smart cities is well documented (Sanchez et al., 2014). Overcoming these challenges also requires technical advancements and industry-wide standardisation, which are not per se related to smart cities. Not surprisingly the two challenges which are placed at level 2 in ISM model, C2 and C8, further lead to 'Standardisation and network flexibility issues (C15)'. IoT consist of a wide variety of different electronic devices embedded with network-connected computers having different processing power, different input-output facilities, and different scale of resources, different connectivity technologies and different communication protocols. Standardisation is a way to overcome this heterogeneity (Weber and Studer, 2016; Atzori et al., 2017; Hui et al., 2017). Hence, the challenge 'Standardisation and network flexibility (C15)' occupies the top level in the ISM hierarchy. This suggests that progress is dependent on good standards, enabling a plug-and-play situation in which projects can focus less on technical issues, and rather on governance and managing complexity.

6. Implications for Theory and Practice

Researchers can use the results to focus their research efforts to reduce the challenges of smart cities, whereas government bodies, policymakers and practitioners can use these results to develop their smart city plans. This work offers following important contributions for theory and implications for practice.

6.1 Contributions for theory

This study provides some key implications for theory in this area of research. First, there are only few research articles on challenges to IoT and identified only few challenges as well as mostly not linked to IoT based smart cities. This research identifies a wide range of challenges for adopting and implementing IoT in smart cities and extended the list of challenges by finding two additional challenges from experts. Furthermore, using an integrated MICMAC-ISM approach the contextual relationships and dependencies among challenges were theorised. These insights can help researchers and practitioners to understand the issues in development of smart cities and not to address challenges in isolation.

Second, this is the first study that has provided an ISM-based framework for all the challenges Therefore, this study provides a methodological contribution to this area of research. This framework provides more in-depth information about the key driving and dependent challenges and their interrelationships. By understanding the interdependencies between challenges, they can be addressed in concert.

6.2 Implications for practice

The findings of this research will help government, policy makers and practitioners in understanding, addressing challenges for adopting and implementing IoT in smart cities. The *use case* for practitioners is that 'Lack of IoT governance and management support (C4)' and 'Complexity problems (C7)' need to be addressed first. A governance framework needs to be outlined and the complexity needs to be decomposed in manageable parts as a start.

Thereafter, a business case needs to be made to address the 'Costing issues (C6)' and choices surrounding the use of technology to deal with 'Security and privacy issues (C1)'. An enterprise architecture needs to be in place to handle the huge amount of data generated from the IoT devices to deal with 'Issues related to data quality and scalability (C10)'.

Once these challenges have been overcome, the other challenges ('Lack of resources (C9)', 'Lack of expertise and knowledge (C11)', 'Stakeholder engagement and collaboration issues (C12)', 'Technological problems (C13)' and 'Lack of business model innovations/solutions (C17)') can be addressed to ensure a good starting point for the individual projects.

Once the smart city foundation and policy is clear, the projects need to be determined to develop the smart city. The individual projects should address the challenges including ‘Lack of resources (C9)’, ‘Lack of expertise and knowledge (C11)’, ‘Stakeholder engagement and collaboration issues (C12)’, ‘Technological problems (C13)’ and ‘Lack of business model innovations/solutions (C17)’. Finally, Smart cities should stimulate organisations like the W3C to develop their standards, which in particular should address ‘Lack of interoperability (C2)’ and ‘Lack of reliability and robustness (C8)’.

IoT based smart cities are in an early stage particularly in developing countries. This research also advances the understanding that some of the critical challenges might be eliminated by plan of action as suggested ISM based structural model. The following significant implications for policymakers and practitioners have been provided for recognising and optimising challenges for adopting and implementing IoT in smart cities.

6.2.1 IoT governance and management support

The governance and management of cities is at the top of the agenda today. Due to the constraints imposed by increased population, environmental needs, energy, mobility, health and well-being, aging, safety, employment and many other aspects, cities and urban areas need to be managed in intelligent way i.e. IoT based smart cities, which could not be possible without effective governance and management support. IoT governance will help in better co-ordination between all stakeholders involved in smart city development.

6.2.2 Developing government vision, policies and practices for IoT based smart cities

IoT will be critical in making smart cities. Therefore, government must focus on enhanced vision for IoT to develop domain specific strategies for IoT including green building, smart-grids, industrial monitoring, agriculture, healthcare, connected homes, telematics and supply chain, etc. Government should focus on policies and practices to guide sustainable smart growth that will meet the needs of citizens and businesses.

6.2.3 Addressing security and privacy issues

The key stakeholders in the IoT would be the citizens, government and the industry. Participation and collaboration of each of the stakeholder at an appropriate stage is essential to address security and privacy issues. Privacy, security, and safety issues lead to one another and primarily go hand-in-hand in terms of data usage. It is necessary to develop a holistic mind-set towards these challenges that take into account the requirements of all stakeholders involved.

6.2.4 Provision of budgets for expansion of IoT infrastructure

Funding and developing infrastructure for IoT remain a challenge, so the governments must focus on allocating budgets for expansion of IoT infrastructure as well as addressing cyber security issues to develop IoT based smart cities. Adequate funds may help removing many of linkage as well as dependent challenges reported in this research.

6.2.5 Improving data quality and scalability

In a truly smart city of the future, everything will be connected and automated. Data gathered from a global-scale deployment of smart-things are the base for making intelligent decisions and providing services. If data are of poor quality, decisions are likely to be unsound. Therefore, government authorities and practitioners must focus in developing new systems and approaches to capture, verify, normalise and assimilate the useful data from the big data generated from the IoT devices. Scalable IoT applications are also essential to monitoring, securing, and managing an increasing number of devices through a proportionate increase in the resources. Therefore, government authorities and practitioners must follow a well framed series of steps, which will facilitate scalability of IoT devices to support smart cities.

6.2.6 Enhancing public awareness

IoT based smart cities could not be possible without the awareness and involvement of public. IoT has the power to make our lives less stressful, fire the engines of productivity, reduce energy consumption, improve healthcare, and create new disruptive business models. Yet, there needs to be a greater awareness of the many ways in which IoT could change society for the better and make it safer too. Greater awareness will help spur demand for new IoT services. Therefore, practitioners and policymakers must engage and raise the awareness of public, which is going to act as a catalyst in solving key issues of cities such as environment, healthcare, transport and security, etc.

6.2.7 Solving legal, ethical and societal concerns

Privacy, security, safety, ethical and societal issues always arise with the innovation and implementation of new technology. Indian government started an initiative of 100 smart cities with the goals to bring quality of life, high tech infrastructure, improved mass transit, pollution free areas, energy efficiency, transparent governance, etc. Resources have been redirected to accomplish this goal, leading to shortages of resources in other areas i.e. ethical concern revolving around smart city implementation. Therefore, a logical planning is needed to address these challenges in IoT based smart city development.

7. Conclusion

IoT can be used to decrease energy use and consumption, tackle pollution, improve traffic flows and safety and security, and achieve a more sustainable consumption and production. Yet, IoT projects encounter many challenges and policymakers and project managers are looking for ways to deal with these challenges and to understand the relationship between them.

Yet, there is a void in literature about the overview of challenges and their interdependencies. This paper contributes to existing literature by identifying and understanding the relationship between the challenges. Through literature review and discussions with experts, 17 critical challenges were identified and their interrelationships analysed. The findings show that IoT is at a nascent stage and challenges such as standardisation and network flexibility issues, interoperability and reliability, and robustness need to be overcome before large scale rollout can happen. Good standards are the basis for creating an interoperable, reliable, flexible, robust, scalable and secure network. Once these challenges are resolved, implementation projects should address the challenges of security and privacy, costing, data quality, scalability, complexity and governance, as these challenges have strong driving power. The main driving challenges are lack of governance and complexity. As these challenges forms the foundation of the ISM hierarchical structure, this suggests that adopting IoT for developing smart cites should focus on creating sound governance and management structures, and on decomposing complexity into manageable parts.

A methodological contribution is the integration of the MICMAC and ISM methods for understanding the challenges for IoT-based adoption and implementation in smart cities. Combining both methods have resulted in a better understanding of the relationships between challenges. MICMAC enables the classification into four categories of autonomous, dependent, linkage, and independent variables, whereas ISM is suitable for identifying contextual interactions. Combining both methods allows for better insight into the challenges and provides directions for addressing them. Our results indicate that combining these methods is a good choice, as it increases insight with only a minimum of additional work. However, the present research also has some shortcomings. The focus was on critical challenges and there might be more challenges that are less critical. In addition, the model was developed using a limited number of experts, and is based on experiences and opinions, which could involve human bias. In the future, a survey may be used to validate the findings of this study.

References

Achi, A., Salinesi, C. and Viscusi, G. (2016), “Innovation capacity and the role of information systems: a qualitative study”, *Journal of Management Analytics*, Vol. 3 No. 4, pp. 333-360.

Ahlmeyer, M. and Chircu, A.M. (2016), “Securing the Internet of Things: a review”, *Issues in Information Systems,* Vol. 17 No. 4, pp. 21-28.

Albino, V., Berardi, U. and Dangelico, R.M. (2015), “Smart cities: definitions, dimensions, performance, and initiatives”, *Journal of Urban Technology,* Vol. 22 No. 1, pp. 3-21.

Arasteh, H., Hosseinnezhad, V., Loia, V., Tommasetti, A., Troisi, O., Shafie-Khah, M. and Siano, P. (2016), “IoT-based smart cities: a survey”, In *2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, Italy, June 6-8,* pp. 1-6.

Ashton, K. (2009), “That ‘Internet of Things’ thing”, *RFID Journal*, Vol. 22 No. 7, pp. 97-114.

Atzori, L., Iera, A. and Morabito, G. (2017), “Understanding the Internet of Things: definition, potentials, and societal role of a fast evolving paradigm”, *Ad Hoc Networks*, Vol. 56 No. 1, pp. 122-140.

Barnaghi, P., Wang, W., Henson, C. and Taylor, K. (2012), “Semantics for the Internet of Things: early progress and back to the future”, *International Journal on Semantic Web and Information Systems (IJSWIS),* Vol. 8 No. 1, pp. 1-21.

Barrero, F., Toral, S., Vargas, M., Cortés, F. and Manuel Milla, J. (2010), “Internet in the development of future road-traffic control systems”, *Internet Research*, Vol. 20 No. 2, pp. 154-168.

Bennett, D., Pérez-Bustamante, D., Medrano, M.L. (2017), “Challenges for Smart Cities in the UK”, In: Peris-Ortiz M., Bennett D., Pérez-Bustamante Yábar D. (eds) *Sustainable Smart Cities, Innovation, Technology, and Knowledge Management. Springer, Cham,* pp. 1-14.

Borgia, E. (2014), “The internet of things vision: key features, applications and open issues”, *Computer Communications,* Vol. 54, pp. 1-31.

Chan, M., Estève, D., Escriba, C. and Campo, E. (2008), “A review of smart homes—Present state and future challenges”, *Computer Methods and Programs in Biomedicine,* Vol. 91 No. 1, pp. 55-81.

Cheng, J., Chen, W., Tao, F. and Lin, C.L. (2018), “Industrial IoT in 5G environment towards smart manufacturing”, *Journal of Industrial Information Integration*, Vol. 10 No. 1, pp. 10-19.

De Jong, M., Joss, S., Schraven, D., Zhan, C. and Weijnen, M (2015), “Sustainable–smart–resilient–low carbon–eco–knowledge cities; making sense of a multitude of concepts promoting sustainable urbanisation”, *Journal of Cleaner Production*, Vol. 109, pp. 25-38.

Díaz, M., Martín, C. and Rubio, B. (2016), "State-of-the-art, challenges, and open issues in the integration of internet of things and cloud computing", *Journal of Network and Computer Applications,* Vol. 67, pp. 99-117.

Evans, D. (2011), "The Internet of Things: how the next evolution of the internet is changing everything", *CISCO White Paper,* Vol. 1 No. 2011, pp. 1-11.

Fernández-Ares, A.J., Mora, A.M., Arenas, M.G., García-Sanchez, P., Romero, G., Rivas, V., Castillo, P.A. and Merelo, J.J. (2017), "Studying real traffic and mobility scenarios for a Smart City using a new monitoring and tracking system", *Future Generation Computer Systems*, Vol. 76, pp. 163-179.

Gade, N.R., Gade, N.R. and Reddy, G.U. (2016), "Internet of Things (IoT) for smart cities-The future technology revolution", *Global Journal of Computer Science and Technology,* Vol. 16 No. 1, pp. 29-34.

Gubbi, J., Buyya, R., Marusic, S. and Palaniswami, M. (2013), "Internet of Things (IoT): a vision, architectural elements, and future directions", *Future Generation Computer Systems,* Vol. 29 No. 7, pp. 1645-1660.

Gürdür, D. and Asplund, F. (2017), "A systematic review to merge discourses: interoperability, integration and cyber-physical systems", *Journal of Industrial Information Integration*, Vol. 9, pp. 14-23.

Hair, J.F., Anderson, R.E., Tatham, R.L. and Black, W.C. (1992). *Multivariate data analysis with readings*. 3rd edn. New York, NY: Macmillan Publishing Company.

Haleem, A., Luthra, S., Mannan, B., Khurana, S., Kumar, S. and Ahmad, S. (2016), "Critical factors for the successful usage of fly ash in roads & bridges and embankments: Analyzing Indian perspective", *Resources Policy*, Vol. 49, pp. 334-348.

Hui, T.K., Sherratt, R.S. and Sánchez, D.D. (2017), "Major requirements for building smart homes in smart cities based on internet of things technologies", *Future Generation Computer Systems*, Vol. 76, pp. 358-369.

Ianuale, N., Schiavon, D. and Capobianco, E. (2015), "Smart cities and urban networks: are smart networks what we need?", *Journal of Management Analytics*, Vol. 2 No. 4, pp. 285-294.

Jun, Z., Simplot-Ryl, D., Bisdikian, C. and Mouftah, H.T. (2011). "The internet of things", *IEEE Communication Magazine,* Vol. 49 No. 11, pp. 30-31.

Khan, R., Khan, S. U., Zaheer, R. and Khan, S. (2012), "Future internet: the internet of things architecture, possible applications and key challenges", In *10th IEEE International*

Conference on Frontiers of Information Technology (FIT), Islamabad, December, pp. 257-260.

Kumar, S., Luthra, S., Govindan, K., Kumar, N. and Haleem, A. (2016), "Barriers in green lean six sigma product development process: an ISM approach", *Production Planning & Control*, Vol. 27 No. 7/8, pp. 604-620.

Kyriazis, D., Varvarigou, T., White, D., Rossi, A. and Cooper, J. (2013), "Sustainable smart city IoT applications: heat and electricity management & Eco-conscious cruise control for public transportation", In *2013 IEEE 14th International Symposium and Workshops on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), Madrid, Spain, June 4-7, 2013*, pp. 1-5.

Lenz, C.E. (2014), "Internet of things: six key characteristics", available at: http://designmind.frogdesign.com/2014/08/internet-things-six-key-characteristics/ (accessed June 19, 21017).

Li, L., Li, S. and Zhao, S. (2014), "QoS-aware scheduling of services-oriented internet of things", *IEEE Transactions on Industrial Informatics,* Vol. 10 No. 2, pp. 1497-1505.

Li, S. and Xu, L.D. (2017), *Securing the Internet of Things*, Syngress Publishing Ltd., MA, United States.

Li, S., Da Xu, L. and Zhao, S. (2015), "The internet of things: a survey", *Information Systems Frontiers,* Vol. 17 No. 2, pp. 243-259.

Li, S., Tryfonas, T. and Li, H. (2016a), "The internet of things: a security point of view", *Internet Research,* Vol. 26 No. 2, pp. 337-359.

Li, S., Tryfonas, T., Russell, G. and Andriotis, P. (2016b), "Risk assessment for mobile systems through a multi-layered hierarchical Bayesian network", *IEEE Trans. Cybernetics*, Vol. 46 No. 8, pp. 1749-1759.

Li, S., Xu, L.D. and Zhao, S. (2018), "5G internet of things: a survey", *Journal of Industrial Information Integration*, Vol. 10, pp. 1-9.

Luo, H., Zhu, M., Ye, S., Hou, H., Chen, Y. and Bulysheva, L. (2016), "An intelligent tracking system based on internet of things for the cold chain", *Internet Research*, Vol. 26 No. 2, pp. 435-445.

Luthra, S. and Haleem, A. (2015), "Hurdles in implementing sustainable supply chain management: an analysis of Indian automobile sector", *Procedia-Social and Behavioral Sciences*, Vol. 189, pp. 175-183.

Luthra, S., Garg, D. and Haleem, A. (2015), “An analysis of interactions among critical success factors to implement green supply chain management towards sustainability: an Indian perspective”, *Resources Policy*, Vol. 46, pp. 37-50.

Luthra, S., Govindan, K. and Mangla, S.K. (2017), “Structural model for sustainable consumption and production adoption—a grey-DEMATEL based approach”, *Resources, Conservation and Recycling*, Vol. 125, pp. 198-207.

Mangla, S., Madaan, J. and Chan, F.T. (2013), “Analysis of flexible decision strategies for sustainability-focused green product recovery system”, *International Journal of Production Research*, Vol. 51 No. 11, pp. 3428-3442.

Mehmood, Y., Ahmad, F., Yaqoob, I., Adnane, A., Imran, M. and Guizani, S. (2017), “Internet-of-Things-based smart cities: recent advances and challenges”, *IEEE Communications Magazine*, Vol. 55 No. 9, pp. 16-24.

Mineraud, J., Mazhelis, O., Su, X. and Tarkoma, S. (2016), “A gap analysis of Internet-of-Things platforms”, *Computer Communications,* Vol. 89, pp. 5-16.

Miorandi, D., Sicari, S., De Pellegrini, F. and Chlamtac, I. (2012), “Internet of things: vision, applications and research challenges”, *Ad Hoc Networks,* Vol. 10 No. 7, pp. 1497-1516.

Nastic, S., Vögler, M., Inzinger, C., Truong, H.L. and Dustdar, S. (2015), “rtGovops: a runtime framework for governance in large-scale software-defined IoT cloud systems”, In *2015 3rd IEEE International Conference on Mobile Cloud Computing, Services, and Engineering (Mobile Cloud), San Francisco, CA ,* pp. 24-33.

Nath, S. and Som, S. (2017), “Security and privacy challenges: Internet of Things”, *Indian Journal of Science and Technology*, Vol. 10 No. 3, pp. 1-5.

Neirotti, P., De Marco, A., Cagliano, A.C., Mangano, G. and Scorrano, F. (2014), “Current trends in smart city initiatives: some stylised facts”, *Cities,* Vol. 38, pp. 25-36.

Nunnaly, J. (1978). *Psychometric theory*. New York: McGraw-Hill.

Obaidat, M.S. (2015), “Key enabling ICT systems for smart homes and cities: the opportunities and challenges”, Keynote speech. In: *Proceedings of the 2014 IEEE International Conference on Network Infrastructure and Digital Content (IC-NIDC 2015), Beijing, China, September 2015.*

Oman, R., Zhou, J. and Lopez, J. (2013), “On the features and challenges of security and privacy in distributed internet of things”, *Computer Networks,* Vol. 57 No. 10, pp. 2266-2279.

Parry, G.C., Brax, S.A., Maull, R.S. and Ng, I.C. (2016), "Operationalising IoT for reverse supply: the development of use-visibility measures", *Supply Chain Management: An International Journal,* Vol. 21 No. 2, pp. 228-244.

Pascual E., J., Yager, R.R. and Guo, B. (2014), "Internet of things: smart things network and communication", *Journal of Network and Computer Applications,* Vol. 42, pp. 118-119.

Patra, L. and Rao, U.P. (2016), "Internet of things—Architecture, applications, security and other major challenges", In *2016 3rd IEEE International Conference on Computing for Sustainable Global Development (INDIACom), Delhi, India, March 16-18, 2013,* pp. 1201-1206.

Perera, C., Zaslavsky, A., Christen, P. and Georgakopoulos, D. (2014), "Sensing as a service model for smart cities supported by internet of things", *Transactions on Emerging Telecommunications Technologies,* Vol. 25 No. 1, pp. 81-93.

Pierce, P. and Andersson, B. (2017), "Challenges with smart cities initiatives–a municipal decision makers' perspective", In *Proceedings of the 50th Hawaii International Conference on System Sciences, Hawaii, USA, June 2-6,* pp. 2804-2813.

Piro, G., Cianci, I., Grieco, L.A., Boggia, G. and Camarda, P. (2014), "Information centric services in smart cities", *Journal of Systems and Software,* Vol. 88, pp. 169-188.

Ray, S.S. and Verma, A. (2016), "Profitable solution to emerging market challenges through internet of things", *Telecom Business Review,* Vol. 9 No. 1, pp. 1-8.

Stojkoska, B.L.R. and Trivodaliev, K.V. (2017), "A review of Internet of Things for smart home: challenges and solutions", *Journal of Cleaner Production*, Vol. 140, pp. 1454-1464.

Sanchez, L., Muñoz, L., Galache, J.A., Sotres, P., Santana, J.R., Gutierrez, V., Ramdhany, R., Gluhak, A., Krco, S., Theodoridis, E. and Pfisterer, D. (2014), "SmartSantander: IoT experimentation over a smart city testbed", *Computer Networks*, Vol. 61, pp. 217-238.

Sheng, Z., Yang, S., Yu, Y., Vasilakos, A., Mccann, J. and Leung, K. (2013), "A survey on the IETF protocol suite for the internet of things: standards, challenges, and opportunities", *IEEE Wireless Communications*, Vol. 20 No. 6, pp. 91-98.

Shin, D.H. (2017), "Understanding the internet of things ecosystem: multi-level analysis of users, society, and ecology", *Digital Policy, Regulation and Governance*, Vol. 19 No. 1, pp. 77-91.

Shrouf, F., and Miragliotta, G. (2015), "Energy management based on Internet of Things: practices and framework for adoption in production management", *Journal of Cleaner Production,* Vol. 100, pp. 235-246.

Sindhu, S.P., Nehra, V. and Luthra, S. (2016), “Recognition and prioritization of challenges in growth of solar energy using analytical hierarchy process: Indian outlook”, *Energy*, Vol. 100, pp. 332-348.

Sta, H.B. (2017), “Quality and the efficiency of data in “Smart-Cities”, *Future Generation Computer Systems*, Vol. 74, pp. 409-416.

Sundmaeker, H., Guillemin, P., Friess, P. and Woelfflé, S. (2010), “Vision and challenges for realising the internet of things”, *Cluster of European Research Projects on the Internet of Things,* European Commission, Europe.

The United Nations Report (2012), *World urbanization prospects, the 2011 revision: highlights*. A Report by United Nations, New York, available at: http://esa.un.org/unpd/wup/pdf/WUP2011_Highlights. Pdf (accessed May 17, 2017).

Urbieta, A., González-Beltrán, A., Mokhtar, S.B., Hossain, M.A. and Capra, L. (2017), “Adaptive and context-aware service composition for IoT-based smart cities”, *Future Generation Computer Systems*, Vol. 76, pp. 262-274.

Vergragt, P.J., Dendler, L., De Jong, M. And Matus, K. (2016), “Transitions to sustainable consumption and production in cities”, *Journal of Cleaner Production*, Vol. 134, pp. 1-12.

Vuletic, T., Whitfield, R.I., Wang, W., Duffy, A., Gatchell, S., Prins, H. and Leer-Andersen, M. (2017), “Improving the creation and management of collaborative networks within the European maritime sector”, *Journal of Industrial Information Integration*, Vol. 8, pp. 22-37.

Warfield, J.N. (1974), “Developing subsystem matrices in structural modeling”, *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 1 No. 1, pp. 74-80.

Weber, R.H. (2009), “Internet of things–need for a new legal environment?”, *Computer Law & Security Review,* Vol. 25 No. 6, pp. 522-527.

Weber, R.H. (2010), “Internet of things–new security and privacy challenges”, *Computer Law & Security Review,* Vol. 26 No. 1, pp. 23-30.

Weber, R.H. (2013), “Internet of things–governance quo Vadis?”, *Computer Law & Security Review,* Vol. 29 No. 4, pp. 341-347.

Weber, R.H. and Studer, E. (2016), “Cyber security in the Internet of things: legal aspects”, *Computer Law & Security Review,* Vol. 32 No. 5, pp. 715-728.

Xu, B., Li, L., Hu, D., Wu, B., Ye, C. and Cai, H. (2018a), “Healthcare data analysis system for regional medical union in smart city”, *Journal of Management Analytics*, Vol. 5 No. 4, pp. 334-349.

Xu, L.D. (2000), "The contribution of systems science to information systems research", *Systems Research and Behavioral Science: The Official Journal of the International Federation for Systems Research*, Vol. 17 No. 2, pp. 105-116.

Xu, L.D., He, W. and Li, S. (2014), "Internet of things in industries: a survey", *IEEE Transactions on Industrial Informatics*, Vol. 10 No. 4, pp. 2233-2243.

Xu, L.D., Xu, E.L. and Li, L. (2018b), "Industry 4.0: state of the art and future trends", *International Journal of Production Research*, Vol. 56 No. 8, pp. 2941-2962.

Xu, X., He, W., Yin, P., Xu, X., Wang, Y., and Zhang, H. (2016), "Business network information ecological chain: a new tool for building ecological business environment in IoT era", *Internet Research*, Vol. 26 No. 2, pp. 446-459.

Yu, X., Nguyen, B. and Chen, Y. (2016), "Internet of things capability and alliance: entrepreneurial orientation, market orientation and product and process innovation", *Internet Research*, Vol. 26 No. 2, pp. 402-434.

Zanella, A., Bui, N., Castellani, A., Vangelista, L. and Zorzi, M. (2014), "Internet of things for smart cities", *IEEE Internet of Things Journal*, Vol. 1 No. 1, pp. 22-32.

Zhang, D., Wan, J., Hsu, C.H. and Rayes, A. (2016), "Industrial technologies and applications for the internet of things", *Computer Networks: The International Journal of Computer and Telecommunications Networking,* Vol. 101 No. C, pp. 1-4.

Zhang, Y., Ren, S., Liu, Y. and Si, S. (2017), "A big data analytics architecture for cleaner manufacturing and maintenance processes of complex products", *Journal of Cleaner Production*, Vol. 142, pp. 626-641.

Zhuhadar, L., Thrasher, E., Marklin, S. and de Pablos, P.O. (2017), "The next wave of innovation—review of smart cities intelligent operation systems", *Computers in Human Behaviour,* Vol. 66, pp. 273-281.

Annexure I

Sample Instrument for Data Collection

COVER LETTER

Name of the organisation………, the Netherlands

Developing Smart Cities Through Internet of Things (IoT)

Dear Participants

Thank you for taking part in responding to questions asked this questionnaire.

This study provides an opportunity for you to become involved in the development of a framework for **'IoT-based Smart Cities'**. Smart Cities are getting world-wide acceptance within information communication technology networks and could potentially change the future of customer services and experiences. However, the issues and challenges associated with IoT-based smart cities need to be considered and addressed in order to ensure their sustainability. This is the context in which our survey is being conducted. The outcome of the survey is aimed at i) selecting the most relevant IoT challenges in developing smart cities and exploring their significance; ii) examining the contextual interactions between the identified challenges and determining their importance levels within the hierarchical structure.

We would like to learn from your experiences and welcome your feedback. Your input will help us establish a framework for IoT-based smart cities.

If you have any questions about the survey, or our plans for how we will use your feedback, please contact

Please note that all responses are confidential and will be used for academic research purposes only. No individuals will be named or contacted as a result of this survey.

We will be extremely grateful for your kind cooperation.

Your sincerely,

…………………………….

SURVEY QUESTIONNAIRE

This questionnaire consists of three sections. Section A aims to collect general information about the respondents and their industries/work settings. Section B is designed to help select key challenges and explore their significance in relation to IoT and the development of smart cities. Section C considers the contextual interactions between the selected challenges.

SECTION A: General Information

Please answer all four of the following multiple choice questions by circling only one answer for each.

1. **What is your professional qualification level?**

(a) Graduate
(b) Postgraduate
(c) Doctorate
(d) Other, please specify…………

2. **How many years of work experience do you have?**

(a) Under 5 years
(b) 5-10 years
(c) 10-15 years
(d) 15-20 years
(e) More than 20 years

3. **How many employees does your organisation have?**

(a) Up to 50 employees
(b) 50-250 employees
(c) 250-500 employees
(d) 500-1000 employees
(e) 1000-5000 employees
(f) More than 5000 employees

4. **Which of the following best describes the business/sector you work in?**

(a) Private Sector
(b) Public Sector
(c) Multinational Corporation
(d) Regulatory Body
(e) Mixed public and private ownership
(f) Other, please specify…………

SECTION B:

Selecting the Most Relevant Challenges and Understanding their Significance in Relation to the Development of IoT-based Smart Cities

Based on related literature and input from experts, we selected 17 challenges from the response sheet. This list is not exhaustive and there may be challenges that fall outside this list that also might influence the efficient development of IoT-based smart cities. Through your expert response, we aim to determine the most relevant challenges and their significance. Please rate the significance of the following challenges on a scale from 1 to 5, where 1 means 'Not significant at all' and 5 means 'Extremely significant' (five-point Likert scale). Tick one box only.

Table A. IoT challenges in developing smart cities and their significance

S. No.	**IoT Challenges in Developing Smart Cities**	**Rating**				
		1	**2**	**3**	**4**	**5**
Literature Input						
1.	Security and privacy issues					
2.	Lack of interoperability					
3.	Legal issues					
4.	Lack of IoT governance and management support					
5.	Ethical and societal issues					
6.	Costing issues					
7.	Mobility problems					
8.	Complexity problems					
9.	Lack of reliability and robustness (system failures)					
10.	Lack of resources					
11.	Data quality and scalability issues					
12.	Lack of expertise and knowledge					
13.	Stakeholder engagement and collaboration issues					
14.	Technological problems					
15.	Public awareness and acceptance issues					
16.	Standardisation and network flexibility issues					
17.	Poor government vision					
18	Lack of business model innovations/ solutions					

SECTION C:

IoT Challenges in Developing Smart Cities and their Contextual Relationships

The responses have been recorded and one challenge ('Mobility problems with a mean score of 2.57) was omitted from the initial list. The next step after finalising the key IoT challenges is to identify the contextual relationships between the challenges. To this end, an SSIM matrix has been constructed (Table B). Please indicate the direction of interaction between the challenges by entering the following four symbols:

V- Challenge i will influence Challenge j,
A- Challenge j will influence Challenge i,
X- Challenges i and j will influence each other, and
O- Challenges i and j are not connected to each other

Table B. SSIM for the challenges to IoT to develop smart cities

S. No.	IoT Challenges in Developing Smart Cities	Contextual Relationships															
		17	**16**	**15**	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
1	Security and privacy issues (C1)																
2	Lack of interoperability (C2)																
3	Legal issues (C3)																
4	Lack of IoT governance and management support (C4)																
5	Ethical and societal issues (C5)																
6	Costing issues (C6)																
7	Complexity problems (C7)																
8	Lack of reliability and robustness (C8)																
9	Lack of resources (C9)																
10	Data quality and scalability issues (C10)																
11	Lack of expertise and knowledge (C11)																
12	Stakeholder engagement and collaboration issues (C12)																
13	Technological problems (C13)																
14	Public awareness and acceptance issues (C14)																
15	Standardisation and network flexibility issues (C15)																
16	Poor government vision (C16)																
17	Lack of business model innovations/solutions (C17)																

Name and signature of respondent:
Title:
Organisation:
Mobile number:
E-mail:
Date:
City:

Annexure II

Iterations Involved in Developing the ISM-Based Hierarchical Model

First Iteration

Element P(i)	Reachability set R(Pi)	Antecedent set A(Pi)	Intersection set R(Pi)∩A(Pi)	Level
1	1,2,3,5,6,8,9,10,11,12,13,14,15,16,17	1,4,6,7,10	1,6,10	
2	2,8,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17	2,8	
3	2,3,5,8,9,11,12,13,14,15,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
4	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17	4,7	4,7	
5	2,3,5,8,9,11,12,13,14,15,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
6	1,2,3,5,6,8,9,10,11,12,13,14,15,16,17	1,4,6,7,10	1,6,10	
7	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17	4,7	4,7	
8	2,8,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17	2,8	
9	2,8,9,11,12,13,15,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	
10	1,2,3,5,6,8,9,10,11,12,13,14,15,16,17	1,4,6,7,10	1,6,10	
11	2,8,9,11,12,13,15,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	
12	2,8,9,11,12,13,15,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	
13	2,8,9,11,12,13,15,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	

14	2,3,5,8,9,11,12,13,14,15,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
15	15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17	15	1
16	2,3,5,8,9,11,12,13,14,15,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
17	2,8,9,11,12,13,15,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	

Second Iteration

Element P(i)	**Reachability set R(Pi)**	**Antecedent set A(Pi)**	**Intersection set R(Pi)∩A(Pi)**	**Level**
1	1,2,3,5,6,8,9,10,11,12,13,14,16,17	1,4,6,7,10	1,6,10	
2	2,8	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17	2,8	2
3	2,3,5,8,9,11,12,13,14,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
4	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17	4,7	4,7	
5	2,3,5,8,9,11,12,13,14,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
6	1,2,3,5,6,8,9,10,11,12,13,14,16,17	1,4,6,7,10	1,6,10	
7	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17	4,7	4,7	
8	2,8	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17	2,8	2
9	2,8,9,11,12,13,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	
10	1,2,3,5,6,8,9,10,11,12,13,14,16,17	1,4,6,7,10	1,6,10	
11	2,8,9,11,12,13,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	
12	2,8,9,11,12,13,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	
13	2,8,9,11,12,13,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	
14	2,3,5,8,9,11,12,13,14,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
16	2,3,5,8,9,11,12,13,14,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
17	2,8,9,11,12,13,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	

Third Iteration

Element P(i)	**Reachability set R(Pi)**	**Antecedent set A(Pi)**	**Intersection set R(Pi)∩A(Pi))**	**Level**
1	1,3,5,6,9,10,11,12,13,14,16,17	1,4,6,7,10	1,6,10	
3	3,5,9,11,12,13,14,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
4	1,3,4,5,6,7,9,10,11,12,13,14,16,17	4,7	4,7	
5	3,5,9,11,12,13,14,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
6	1,3,5,6,9,10,11,12,13,14,16,17	1,4,6,7,10	1,6,10	
7	1,3,4,5,6,7,9,10,11,12,13,14,16,17	4,7	4,7	
9	9,11,12,13,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	3
10	1,3,5,6,9,10,11,12,13,14,16,17	1,4,6,7,10	1,6,10	
11	9,11,12,13,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	3
12	9,11,12,13,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	3
13	9,11,12,13,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	3
14	3,5,9,11,12,13,14,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
16	3,5,9,11,12,13,14,16,17	1,3,4,5,6,7,10,14,16	3,5,14,16	
17	9,11,12,13,17	1,3,4,5,6,7,9,10,11,12,13,14,16,17	9,11,12,13,17	3

Fourth Iteration

Element P(i)	**Reachability set R(Pi)**	**Antecedent set A(Pi)**	**Intersection set R(Pi)∩A(Pi)**	**Level**
1	1,3,5,6,10,14,16	1,4,6,7,10	1,6,10	
3	3,5,14,16	1,3,4,5,6,7,10,14,16	3,5,14,16	4
4	1,3,4,5,6,7,10,14,16	4,7	4,7	
5	3,5,14,16	1,3,4,5,6,7,10,14,16	3,5,14,16	4
6	1,3,5,6,10,14,16	1,4,6,7,10	1,6,10	
7	1,3,4,5,6,7,10,14,16	4,7	4,7	
10	1,3,5,6,10,14,16	1,4,6,7,10	1,6,10	
14	3,5,14,16	1,3,4,5,6,7,10,14,16	3,5,14,16	4
16	3,5,14,16	1,3,4,5,6,7,10,14,16	3,5,14,16	4

Fifth Iteration

Element P(i)	**Reachability set R(Pi)**	**Antecedent set A(Pi)**	**Intersection set R(Pi)∩A(Pi)**	**Level**
1	1,6,10	1,4,6,7,10	1,6,10	5
4	1,4,6,7,10	4,7	4,7	
6	1,6,10	1,4,6,7,10	1,6,10	5
7	1,4,6,7,10	4,7	4,7	
10	1,6,10	1,4,6,7,10	1,6,10	5

Sixth Iteration

Element P(i)	**Reachability set R(Pi)**	**Antecedent set A(Pi)**	**Intersection set R(Pi)∩A(Pi)**	**Level**
4	4,7	4,7	4,7	6
7	4,7	4,7	4,7	6