A socio-technical analysis of internet of things development: an interplay of technologies, tasks, structures and actors

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Abstract

Purpose – *Prior research on the area of internet of things (IoT) development has primarily emphasized the overview descriptions and rarely investigated this area from a socio-technical standpoint. However, IoT development is a socio-technical ensemble, which requires analysis with a simultaneous focus on both technical and non-technical issues. Hence, this paper aims to analyze the development of IoT through the lens of the socio-technical system (STS) theory.*

Design/methodology/approach – *Having reviewed the STS theory, the key components of the IoT development are identified using prior literature review and semi-structured interviews with experts involved in the Iranian IoT development effort.*

Findings – *As a result, this paper provides insight into the key socio-technical issues in the IoT development classified under technology, tasks, structure and actors as four components of STS. Moreover, the close connections between the components are clarified.*

Originality/value – *This research is among the earliest studies, which use the STS theory to investigate the IoT development. The conducted socio-technical analysis of this study may assist the governments, industries and entrepreneurs as the chief stakeholders of IoT development to better align their actions with each other and achieve a balance between both technical and social sides.*

Keywords *Internet of things, IoT development, Socio-technical systems theory, Socio-technical perspective, Qualitative research*

Paper type *Research paper*

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1. Introduction

In recent decades, digital technologies have profoundly changed the world and are becoming a powerful enabler for stimulating long-term development (Malaquias *et al.*, 2017). As an emerging technology, the internet of things (IoT) is capable of realizing the digitization of our society and economy effectively (Yaqoob *et al.*, 2019; Kshetri, 2017). IoT, a novel paradigm that has swiftly drawn attention in modern economics, allows for a drastic enhancement in the daily life of both private and business users. Aiming to create a novel intelligent era of internet, IoT integrates both physical and digital worlds in one single ecosystem (Atzori *et al.*, 2010; Borgia, 2014; Lee and Lee, 2015; Mishra *et al.*, 2016).

IoT is presumed among those technologies expected to exponentially grow in the forthcoming decade. As estimated by Gartner and other prestigious reports, 8.4 billion IoT devices, which were in-use in 2017 will reach 20.4 billion by 2020 (Kim and Kim, 2016). Besides, according to the International Data Corporation, it is expected to increase the investment in the IoT industry from $800bn to $1.4tn by 2021. Therefore, IoT is one of the forefront technologies that many countries have been invested or are planning to invest on as their future innovation driver (Saarikko *et al.*, 2017).

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Generally speaking, IoT has become an increasingly vital enabler for economic development. Nevertheless, the transition to this sophisticated technology is a challenging process requiring a prudent vision, strategy and policy (Mohammadzadeh *et al.*, 2018). Given the broad scope of the IoT, it is of great importance to clarify the current state and usher the future research subsequently.

From one part, IoT has been mainly discussed with a more focus on the technical aspect of design, such as network development (Shin, 2014). From another part, the majority of prior studies on non-technical aspects of the IoT development have addressed basic concepts, applications and challenges of IoT (Borgia, 2014; Ng and Wakenshaw, 2017; Atzori *et al.*, 2010; Dutton, 2014; Lee and Lee, 2015; Gubbi *et al.*, 2013; Lu *et al.*, 2018; Mishra *et al.*, 2016; Liu *et al.*, 2017). While fewer efforts have focused on how IoT should be developed as a socio-technical phenomenon. Indeed, to our knowledge, few scholars have investigated the IoT development taking a socio-technical perspective (Shin, 2014; Shin and Park, 2017; Krotov, 2017). Shin (2014) proposed a socio-technical framework by which IoT development in Korea was analyzed. Additionally, the obstacles associated with designing components of IoT were explained in his study, followed by some recommendations to overcome the challenges. Later, having applied a multi-level perspective, Shin and Park (2017) investigated the IoT ecosystem encompassing users, society and ecology. In another study, Krotov (2017) provided insight into the socio-technical analysis of IoT development by presenting a framework including triple environments, namely, technological, physical and socio-economic environments. As a result, merely a limited number of studies have investigated the socio-technical analysis of IoT development. In other words, the prior research is subjected to criticisms about their weakness in presenting a socio-technical framework based on the socio-technical system (STS) theory.

A socio-technical perspective can provide a comprehensive framework in which a variety of human-technology interactions in the IoT development emerge. Analyzing the IoT development from a socio-technical lens will yield prominent insights into technology development as a multifaceted phenomenon. The analysis necessitates going beyond the technical aspects and investigating the phenomenon by focusing more on the non-technical issues facing the IoT development. For this purpose, in line with the STS theory, the current study makes an attempt to explore how can the IoT be developed as a STS?

The remainder of this paper is structured as follows: Section 2 provides a literature review on the definition of the IoT and STS theory. Section 3 describes the research method used in this study. Section 4 presents the results in which the socio-technical framework of the IoT development is elucidated. In Section 5, some practical implications are proposed. Finally, Section 6 concludes the paper.

2. Literature review

2.1 Internet of things definition

According to radio frequency identification (RFID) group viewpoint, IoT is defined as "the worldwide network of interconnected objects addressable based on standard communication protocols" (Gubbi *et al.*, 2013). IoT pledges a new technological paradigm, by connecting anything and anyone at any time and any place, using any path/network and any service (Yaqoob *et al.*, 2019; Atzori *et al.*, 2010). IoT has several fields of application such as healthcare, transportation, smart industry, logistics, energy, personal life domain, smart cities, agriculture and emergency management (Atzori *et al.*, 2010; Lee and Lee, 2015; Mishra *et al.*, 2016).

The concept of IoT is many-folded, meaning that it embraces many different technologies, services and standards (Takano and Kajikawa, 2019; Borgia, 2014). Indeed, IoT is comprised of sophisticated sensors, actuators and chips embedded in physical things. These things are connected together through a global internet-based technical architecture

(Gubbi *et al.*, 2013; Kim and Kim, 2016). According to Atzori *et al.* (2010), the salient capability of the IoT is the integration of several collaborative and communication technologies allowing for comprehensive data collection.

This research considers the IoT beyond its merely technical sides. Indeed, focusing on STS theory, this study investigates both technical and non-technical issues and aspects in IoT development to shape its development path effectively.

2.2 Socio-technical system theory

Socio-technical scholars believe that development of any kind of information system stems from a particular focus on the multifaceted networks of institutions, actors and technological infrastructure. Designing an STS refers to not only technical solutions (according to the latest technology) but also new business opportunities and legal, as well as social expectations and requirements (Maguire, 2015). Similarly, Bostrom and Heinen implied that every organizational work system consists of two interactive parts, namely, technical and social subsystems. The technical subsystem includes technology, artifacts, processes, tasks, procedures and the physical environment. While, the social subsystem comprises elements such as structure and people (with their viewpoints, behaviors and relationships) (Bostrom and Heinen, 1977). According to the STS theory, although technical and social systems are closely interrelated, they are distinct from each other by nature. While technical systems aim to attain specified performance parameters, social systems consist of the human being with an unpredictable behavior (Walker *et al.*, 2008). According to Shin (2014), the investigation of systems is traditionally dominated by technical aspects. Nonetheless, the socio-technical perspective argues that all the aspects of systems should be considered including the technical artifacts, market, rules and the users for whom the system is developed.

According to another approach, actors, institutions and technologies are the key elements, which constitute an STS (Fuenfschilling and Truffer, 2016). In this framework, actors (individuals, firms, consumers, citizens, policymakers, etc.) are “the entities that make decisions and involve in processes by performing different roles.” Institutions are “the formal rules, regulations, procedures, decision processes, etc., in a society or more formally, are the humanly devised constraints that shape human interaction.” The institutions’ main role in a society is to reduce uncertainty by establishing a stable structure to human interaction. The technical system “refers to all technical elements in the system (infrastructure, technologies, artifacts and resources) and physical flows and processes” (Fuenfschilling and Truffer, 2016).

The STS theory emphasizes the dynamic and open relationship between the system and the environment, followed by the significance of environmental factors such as institutional norms and regulations, tasks, decision processes and hierarchies (Baxter and Sommerville, 2011).

Briefly, STS theory was considered appropriate to analyze the IoT development due to the following reasons: first, the STS provides a comprehensive framework to investigate emerging issues with reciprocal social and technical dimensions (Mumford, 2006). IoT, as a socio-technical phenomenon, also comprises both technical and social components. Therefore, STS theory best matches with the IoT development. Second, the STS theory is premised on the open system’s assumption (Baxter and Sommerville, 2011). Unlike the closed systems with no interactions with the environment, open systems exchange information effectively over the boundaries. This particularly applies to the IoT systems that are affected by various actors, such as government, legislative environment, pioneer industries, innovative startups, etc. (Shin and Park, 2017).

3. Methodology

The foundation of this research is a literature review and semi-structured interviews with 19 Iranian experts involved in the IoT development activities. Qualitative data analysis methods are known as the most appropriate tools in investigating the socio-technical phenomena. In Table I, the participants ranged from academic researchers (6 participants) and industry practitioners (7 participants), to government officials (6 participants), all of which expert in the IoT development area.

In most cases, participants were visited at their organizations, and in other cases, the meetings took place at other venues, at the request of the participants. Prior to the initiation of each interview, interviewees gave their consent to have the sound of the whole conversation digitally recorded and to the creation of transcripts and findings for scientific purposes and international publications. The interviews, which lasted about 90 min (the average time), were recorded and transcribed. Then, a thematic analysis was conducted based on a coding scheme informed by the theoretical assumptions. To analyze the secondary data obtained from the literature, a content analysis was performed. All the first (interviews) and secondary (literature) data were coded using the MAXQDA. Then, the coded texts were extracted in a systematized form to analyze the development of IoT. The transcripts were read and re-read accurately, and line-by-line coding was conducted. The codes extracted from the line-by-line coding were summarized into a coding source by which a categorization was performed by analyzing both the content and context. Finally, all the collected data were coded into MAXQDA, and final themes were discovered.

Having contributed to various aspects of IoT, as mentioned earlier, both first and secondary data were used for analysis. Specifically, secondary data were used for the most part for explanation of IoT technology in terms of its architecture, network, hardware, software and applications/services (Section 4.1.1 to Section 4.1.5, respectively), IoT standardization

Table I Data collection and analysis

Sector	*Education level*	*Education field*	*Responses*
Government	PhD 3 Master 3 Bachelor –	Electrical engineering Industrial management Business/Entrepreneur management IT management ICT law and Communications law	6
Industry (smart city, healthcare, energy and smart home)	PhD 3 Master 2 Bachelor 2	IT management IT engineering Executive management Software engineering Electrical engineering	7
Academia	PhD 6 Master – Bachelor –	Software engineering Hardware engineering Computer science	6
Method	Sections of analysis		Data source
Content analysis	IoT technology: architecture (Section 4.1.1), network and security (Section 4.1.2), hardware (Section 4.1.3), software (Section 4.1.4) and application and services (Section 4.1.5) IoT institutions: standardization (Section 4.3.1) and regulatory (Section 4.3.2) IoT actors: entrepreneurs (Section 4.4.3) and customers (Section 4.4.4)		Secondary data (academic papers from literature)
Thematic analysis	IoT technology: network and security (Section 4.1.2), hardware (Section 4.1.3) and software (Section 4.1.4) IoT institutions: standardization (Section 4.3.1), regulatory (Section 4.3.2), research and development (Section 4.2.2), strategic plan (Section 4.2.1) and education (Section 4.2.3) IoT actors: government (Section 4.4.1) and industry (Section 4.4.2)		First data (interviews)

(Section 4.3.1), regulatory (Section 4.3.2) and IoT actors in terms of entrepreneurs (Section 4.4.3) and customers (Section 4.4.4). On the other hand, first data were primarily applied for the elucidation of IoT hardware and software (Section 4.1.3 and Section 4.1.4, respectively), IoT tasks in terms of strategic planning (Section 4.2.1), R&D (Section 4.2.2) and education (Section 4.2.3), IoT structure in terms of standardization (Section 4.3.1) and regulatory (Section 4.3.2) and IoT actors as government and industry (Section 4.4.1 and Section 4.4.2, respectively). Table I shows a summary of data collection and analysis.

4. Results (socio-technical analysis of internet of things development)

Under the STS framework presented by Bostrom and Heinen (1977), this study conceptualizes the IoT development as a socio-technical phenomenon; that is, a network of four interactive elements, namely, technology, tasks, structure and actors each of which includes some issues. Figure 1 depicts the quadruple socio-technical elements of IoT development. In Figure 1, components of the IoT development as an STS are divided into two main groups, namely, technical subsystem and social subsystem.

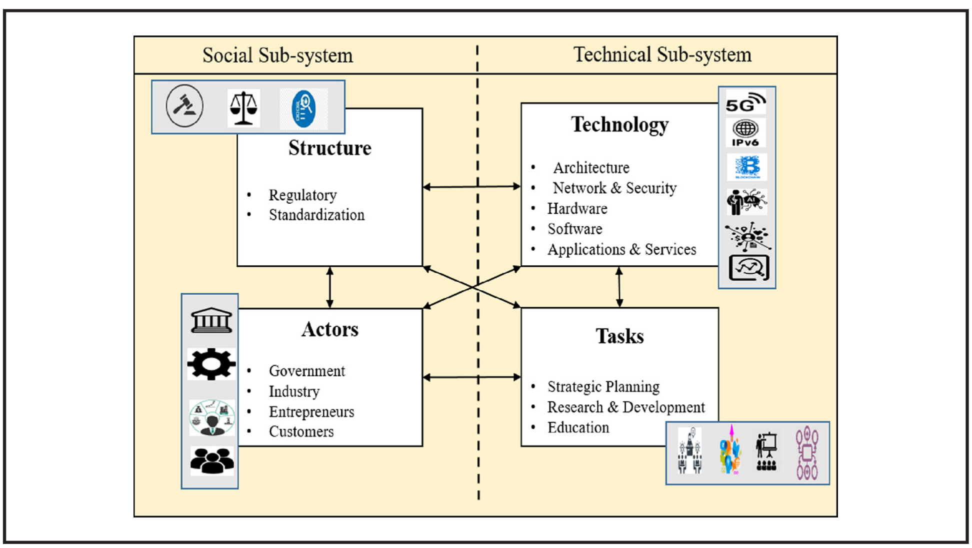
4.1 Technology

4.1.1 Architecture. The IoT architecture is based on a five-layer structure, including a sensing control layer, networking layer, resource management layer, information processing layer and application layer (Atzori *et al.*, 2010; Shin, 2014). For the IoT context, an open architecture should be followed to support various network applications. Moreover, it also consists of a scalable, secure and semantic representation middleware to promote data integration with the internet.

4.1.2 Network and security. Information and communication technology (ICT) experts frequently explained that the most appropriate network infrastructure for the IoT services is the high-speed fifth-generation wireless (5G) by which latency is decreased, and coverage is enhanced remarkably. 5G is capable of transmitting data 20 times more swift than its fourth-generation (4G) predecessors, with less than one-tenth of the latency (Hristov, 2017).

In this regard, according to the Ministry of Communication and Information Technology (MCIT) of Iran, the operational roadmap for 5G implementation has been provided.

Figure 1 IoT development as a socio-technical phenomenon



Additionally, as the director of communication regulatory authority of Iran has announced, Iran is currently providing the required infrastructures for 5G telecom network. In this regard, some preliminary actions like providing bandwidth and regulation are underway.

From another side, participants stated that data security could be enhanced by using powerful technologies such as blockchain and internet protocol version 6 (IPV6). The wireless communication of IoT devices can be secured dramatically by using the blockchain mechanisms. Given the fact that IPV6 is considered the most appropriate protocol for sophisticated and distributed network applications in IoT (Banerjee *et al.*, 2018), participants seriously declared that the network transition from IPV4 to IPV6 is a crucial part of a successful IoT implementation. Having finished the trial and pilot projects of IPV6 development, information technology organization of Iran will complete the full implementation of IPV6 within the next two years.

4.1.3 Hardware. There are four groups of supportive technologies for the IoT, which encompasses IPV6, sensor technology, communication technology and information processing technology. The first technology, IPV6 is used to identify things effectively. A sensor is a promising technology for dynamic information sensing. Communication technology is responsible for transmission of data sensors, while the information processing technology integrates a variety of processing technologies and techniques such as intelligent computation, data mining, optimized algorithm, machine learning, etc (Atzori *et al.*, 2010; Lee and Lee, 2015; Borgia, 2014; Shin, 2014).

Additionally, hardware components play a pivotal role in connecting various IoT objects such as portable computers, smartphones, wearable devices, RFID tags, RFID readers, wireless sensors, etc (Krotov, 2017).

According to participants, providing a standard platform for design and assembly of the IoT hardware necessitates paying adequate attention to reliability, availability, and maintainability in system design and development. This allows for a robust infrastructure, which prevents probable malfunctions in equipment and systems.

4.1.4 Software. The software is becoming the core of the IoT ecosystem. In this vein, in accordance with participants' declaration, most effort should be concentrated on the development of a standard platform for data aggregation, storage and analysis. Some Iranian companies made an effort to build and localize an analysis and management platform to implement IoT plans. This software platform has the ability to connect to a variety of sensors by which large-scale data from different sensors can be gathered and analyzed. This platform can be applied in managing urban energy and resource, incidents related to emergency services and fire-fighting, urban green space, buildings and smart hospitals and complexes and all related matter.

Taking another perspective, huge amounts of data generated by IoT sensors and devices should be processed and stored. For doing so, big data analytics is seen as a helpful solution. These tools are capable enough of handling large volumes of data generated from IoT devices, which create a continuous stream of information. From another side, handling and processing huge data streams in real-time necessitates cloud/fog computing capabilities (Lee and Lee, 2015; Shadroo and Rahmani, 2018). Moreover, as participants stated, many IoT devices generate latency or time-sensitive data, which requires filtering or discarding irrelevant data. This can be achieved by using key technologies, platforms and tools for data analytics such as business intelligence (BI), artificial intelligence (AI) and data mining techniques.

4.1.5 Applications and services. IoT has a broad application domain by which a variety of personal, social, medical, environmental and logistics issues can be tackled. The diverse applications can be grouped into three major domains, namely, industrial domain, smart city domain and health well-being domain. Each domain is not isolated from the others but it is partially overlapped, as some applications are shared (Atzori *et al.*, 2010; Borgia, 2014; Shin, 2014; Lee and Lee, 2015).

4.2 Tasks

4.2.1 Strategic planning. Strategic perspective plays a central role in facilitating the IoT development in Iran. It should be highlighted that Iran ICT outlook requires an update with the emergence of the key basic technologies such as IoT. Further, the alignment of policies for IoT development with Iran outlook is considered a vital need. From the operational aspect, as MCIT has declared, designing the phase zero project to conduct the feasibility analysis, and also providing an operational roadmap should be attached a high significance and considered seriously. From another part, strategic planning is pertinent to futurology, by which it is striven for the foresight to improve the formal education system and explore career prospects in the IoT field for the near future. With respect to the formal education aspect, participants believed that Iran's higher education system requires reconsideration in accordance with the industry demands to enable students to enhance their practical skills. The career prospects aspect refers to the identification of required jobs for the IoT area and providing a job description and determination of required skills for the defined jobs.

4.2.2 Research and development. Participants stated that establishing specialized units for the provision of technological infrastructure brings a tangible acceleration for IoT development resulting from decreasing redundancy and increasing efficiency. From another part, it should be noted that the integration and consolidation of the specialized units' actions necessitate the inauguration of a consortium as central coordination.

R&D centers are significantly effective not only in ICT specialized units but also in coordinating the IoT initiatives in Iran. Indeed, R&Ds allows for both developing the particular ICT units through their specialization around core technologies, and coordination of all the conducted activities. For this purpose, Iran has launched many specialized groups, forums and research centers such as Iran IoT research center, Iran IoT forum, IoT academy of Iran and IoT research labs in major universities to enhance and accelerate the IoT development.

4.2.3 Education. Given the high significance of training and education, opportunities should be provided for IoT stakeholders to extend their knowledge level regarding this technology through both short term and long term programs. Associated with the short term programs, holding congress and conferences in the IoT development field was introduced a necessary issue by the participants. Hence, Iran is currently hosting many national and international IoT conferences. Besides, serving a largely young and educated population, Iran's tech startups can be on the rise. In this respect, different startup communities have been launched in major Iranian cities by which useful startup weekends or summer IoT events and competitions could be provided to educate the Iranian society on the opportunities they have.

With respect to long term programs, the workforce should be provided with the proper training for IoT strategy by which reaching new markets will be more possible and flexible. For this purpose, finding and hiring talented experts in IoT is in great demand.

4.3 Structure

4.3.1 Standardization. Various technical and operational standards outline the design of IoT elements and ensure their interoperability (Krotov, 2017; Borgia, 2014). According to the deputy Telecoms Minister of Iran, setting up proper standards for securing IoT devices is prioritized over all other factors. More specifically, standards cover various sectors, and broad scope of issues ranging from time latency, naming the things, sensors relations, barcode identification, to issues such as specifications of the maximum allowed wavelength and frequency of sensors. In addition, other issues such as architecture, communication protocols, security and privacy, data ownership and public service platform also demand standardization. Iranian experts involved in the IoT development have increasingly emphasized that international standards for IoT development should be adjusted and localized according to the requirements and conditions of our context. It is also required to reduce standardization overlap and the risk of lack of interoperable solutions.

4.3.2 Regulatory. Regulatory processes and governance structure should be reconsidered with the emergence of the IoT. Some of the key issues of governance and regulation include accountability for failures and data breaches, determining who sets standards, rethinking data protection policy and effecting institutional changes to cope with the scale of the IoT and its applications (Dutton, 2014; Shin, 2014).

As Iranian ICT-law experts clarified, regulatory issues toward IoT development are related to general law principles and specific legal issues for ICT and IoT contexts. With regard to general legal principles, the following requirements should be considered in Iran: the commercial advertisements system for IoT context should be upgraded appropriately; the awareness level of IoT users should be raised in terms of quality, quantity and pricing system of IoT services; the process of making complaint and conflict resolution of users for IoT context should be facilitated using electronic methods. ICT-oriented legal issues for IoT context are related to a group of issues consisting of licensing and spectrum management, addressing and numbering, switching and roaming, security and privacy. Besides, participants mentioned intellectual property and civil and criminal liability as other crucial law-oriented issues toward the successful development of IoT.

4.4 Actors

4.4.1 Government. IoT applications often enter realms governed by specific regulatory bodies and legislature (Krotov, 2017; Shin, 2014). For emerging economies such as Iran moving from the industrial age to the knowledge-based economies, the government should support the private sector and startups by national planning and enacting business-related laws and regulations (in areas such as corporate structuring and tax laws) and ICT-related laws (such as intellectual property rights and similar areas). This allows for paving the way for entrepreneurs to innovate and come up with product ideas, and encouraging investors to consider technology area as a serious investment tool. Indeed, the Iranian government should provide an effective communication platform to facilitate the private sector's presence and engagement in the IoT development. To achieve this, the government should begin to push the society for entrepreneurship by allocating grants to growing the tech area by which a great opportunity can be provided for new job creation for Iranian citizens.

More importantly, the government should profoundly get involved in crucial issues such as policymaking, goal-setting, strategic planning and regulating. In this vein, the government should place increasing emphasis on supporting users to ensure critical issues such as privacy, intellectual property, competition and consumer law, human capital and employment, etc (Shin and Park, 2017; Ng and Wakenshaw, 2017). Participants stated that as long as the government does not play a major role in the matter and there are no clear rules and regulations, no window for implementing IoT would be opened.

4.4.2 Industry. Industry is a good partner for the government to develop new technologies efficiently. Iranian industries should be encouraged to get involved in the IoT development through receiving financial and non-financial support of Iran's Government according to which development path would be facilitated. Unlike the government, industries (in the private sector) contribute to the IoT development through being leading in innovation and execution. In other words, only the private sector should take the business-centric role in market-oriented situations. In Iran, various industries are involved in the IoT development projects; such as systems development companies, telecom equipment manufacturers, telecom companies, and Iran's mobile network operators such as mobile communication company of Iran, MTN-Irancell, RighTel, ICT service providers (cloud computing providers), ICT consulting companies, etc. These ICT-oriented industries are responsible for developing applications and implementing technologies such as IT broadband, wireless networks, and also providing data centers and designing platform for IoT data aggregation and processing. They also should ensure security and privacy of data, services and entire IoT system in terms of a series of properties, such as confidentiality, integrity, authentication, authorization, availability and privacy (Borgia, 2014). One key driver for increasing digital engagement towards network infrastructure can be the emergence of competition between Iran's telecom providers.

4.4.3 Entrepreneurs. Entrepreneurs make a major contribution to the development of the IoT. Motivated by their desire for self-gain, and empowered by technical knowledge, business experience and intuition, the entrepreneurs develop new business models particularly for the IoT context (Krotov, 2017). As the most significant contributions of entrepreneurs in the IoT development, business model design encompasses the following key components: customer segments, customer relationships, customer channels, key partnerships, core competencies, key resources, key activities, value proposition, revenue streams and cost structure (Dijkman *et al.*, 2015; Metallo *et al.*, 2018).

4.4.4 Customers (users). While it is traditionally presumed that customers are not aware of what they require until being offered by service providers, most business models are designed based on a core customer concept (Krotov, 2017). In other words, customers are a significant element of the IoT development ecosystem, thereby should receive sufficient support from the IoT service providers. For this purpose, the IoT users should be notified of what, and how of IoT applications and their performance. In this vein, social media can be a key enabler in building the culture of IoT adoption and usage. From another side, there are privacy concerns on the type and amount of information gathered about individuals, while they might not even be aware of (Shin and Park, 2017; Sicari *et al.*, 2015). Indeed, as serious security threats arise from remotely controlling the physical objects, there is a huge demand for the establishment of consumer privacy groups to support the IoT users (Krotov, 2017).

4.5 Relationships between socio-technical system components for internet of things development

STS components are strongly interconnected. The components and their accompanied relationships for Iranian IoT development have been interpreted in Table II.

5. Discussion

This paper contributed to advancement of the IoT development phenomenon by applying the concept of STSs. Such a theory-oriented perspective yielded a more diversified analysis of IoT development as a socio-technical ensemble. The findings of this study, which resulted from an interrelated set of technology, market, society and institutional factors, provide implications for both practitioners and academia.

The government can be beneficiary of practical guidelines, such as insight into the IoT strategies, policies, and market structuring at national and international levels. The government should involve in the market in a focused and strategic manner. The government's actions are critically important to trigger or guide private sector development and link them with the government's sector objectives. This entails supporting the private sector financially by offering tax credits, subsidies and low-interest loans to stimulate innovation dramatically (Shin, 2014). Moreover, the government should provide special programs to raise public awareness, improve the IoT literacy level and empower

Table II STS analysis for Iranian IoT development

Socio-technical components	*Definition*
Actor	Actors include Iranian government, Iranian industries, Iranian entrepreneurs and customers who all considered as stakeholders in terms of caring out, influencing or getting influenced by the IoT development
Structure	The structure covers both systems of authority and workflow. Regarding the authority, structure refers to required regulations and rules for developing IoT such as ICT-oriented and general legal issues. With respect to workflow, the structure is related to standardization for actions associated with IoT development
Task	Task elucidates the way in which IoT development effort will get done in Iran. It consists of strategic planning, R&D and education (brainware)
Technology	Technology refers to technical infrastructure required for IoT development mainly including network, hardware and software
Component relationships	Interpretation
Actor-structure	Government creates an appropriate structure (rules and standard for IoT) by which industries and entrepreneurs are supported and navigated to provide innovative ICT solutions and propose smart IoT services, respectively. Customers, as another actor, are also affected by the structure particularly in terms of security and privacy, and civil and criminal liability in using IoT services
Actor-task	Actors perceive and undertake tasks or train to perform tasks. Government plays a pivotal role in strategic planning in terms of clarifying the IoT development path. Industries facilitate IoT development through coordinating particular ICT groups and R&Ds, followed by instructing IoT knowledge. Entrepreneurs can develop their business model by receiving consultancy from R&Ds. Customers can be a peripheral beneficiary of the education task by raising their awareness about IoT applications and services
Actor-technology	Government is responsible for providing and improving the core technological infrastructure (e.g. 5G, IPV6, etc.). Industries seek innovative solutions (based on AI, BI and big data analytics) for creating a platform for aggregation and analysis of IoT data. Thus, government and industries should collaboratively provide the technical requirements. Government and entrepreneurs both involve in the provision of IoT applications and services, while customers use the services
Task-technology	Development of IoT applications and services entails goal-setting, preparing a roadmap, and action plans, and implementing zero phase projects (e.g. smart metering for the energy sector, etc.). Additionally, specialty clusters in different ICT areas should be established and promoted. Educational projects should also cover all the required technological areas
Task-structure	All the tasks associated with IoT development should be aligned with the enacted rules and regulations and established standards for IoT development and usage
Technology-structure	Established standards cover a variety of ICT areas (from security and privacy to switching and numbering, etc.) and determine the allowed boundaries. Besides, technological infrastructure should have an obvious alignment with the ICT-oriented rules such as privacy and security

self-regulation. In regard to strategic considerations, the government should also concentrate on the following suggestions: to allocate a remarkable funding to the R&D in the AI and big data (as two cornerstones of the IoT implementation), to establish start-up firms around key universities and research centers (Hristov, 2017; Shin and Park, 2017), and to enhance the performance of network and security by providing the sufficient infrastructure for the 5G and blockchain technologies. In terms of regulatory aspect, government and policymakers are highly recommended to create a robust legal framework specifically for IoT development. The favorable legislation framework should cover the fundamental legal principles associated with the IoT context including intellectual property, civil and criminal liability, followed by privacy rules. Additionally, an adequate focus on the standard-setting is required to ensure interoperability. This process should follow a multi-stakeholder approach (Shin and Park, 2017; Dutton, 2014) in which all the relevant actors should be involved and contribute to the standardization. This allows for the preparation of the required institutional infrastructure offering an opportunity to accelerate the IoT development.

From another side, it seems essential for the IoT service providers and ICT designers to follow a human-center approach in designing the IoT services and put humans before technology. In addition, it is recommended to the IoT providers and industry associations to hold seminars and exhibitions to promote their brand and services. This could also provide an opportunity to enabling users to be informed about the IoT services, and legal rights in using the IoT services.

In addition to practical contributions, the theoretical contributions from this study are also summarized. Briefly, this study contributes to the interpretive approach of the STS theory by investigating the IoT development phenomenon of a particular context. While a socio-technical framework has typically been applied in an organizational context to provide organizational management, such a framework has rarely been used at the macro level for a comprehensive analysis of emerging technologies. Limited research has investigated the details of the theory components. Substantial research using the STSs theory has somewhat investigated components in a discrete way. Consequently, from a theoretical perspective, this study makes some contributions to the body of knowledge in the area of technology development and management. Indeed, this research is among the earliest studies, which use the STS theory to investigate the IoT development. Overall, this research provided knowledge about how to investigate the IoT development as a socio-technical phenomenon by creating an interaction between institutions, actors and technologies.

6. Conclusion

The objective of this paper was to analyze IoT development from a socio-technical lens. Through a review of literature, and semi-structured interviews, the socio-technical issues relevant to IoT development in Iran were explored corresponding to four interacting elements of STS theory, namely, technology (architecture, network and security, hardware, software, applications and services), tasks (strategic planning, R&D and education), structure (standardization and regulatory) and actors (government, industry, entrepreneurs and customers). As mentioned earlier, these quadruple pillars must be considered together and not only in isolation. The actor-structure relationship highlights the concept of governance by which the Iranian Government has the authority to clarify the regulatory and legal issues as supportive guide for the private sector. The focus of the actor-task relationship is mostly on stakeholder analysis and roles. In this regard, the actor-network theory could be put forward as a tool for more profound implications towards interactions among different actors. Regarding the actor-technology connection, it should be notified that not only private sector (industries and entrepreneurs) involve in providing the technological infrastructure but also Iranian government has a leading role in the provision of network and security infrastructure as the backbone for development. With respect to the task-technology relationship, a robust alignment should be demonstrated between the technological elements (network, software, etc.) and content of educational programs, and conducted actions in specialty ICT groups in R&Ds to ensure an effective interconnection. The task-structure connection is among the least interconnected relationships. Finally, technology-structure relationship is of high significance because of the strong necessity of defining and contextualizing a comprehensive standard exclusively for the IoT development area, and also paying adequate attention to ICT law aspects such as civil and criminal liability particularly in application areas such as smart home (possibility of theft) and smart transportation (possibility of occurring an accident by automatic connected cars). To perform a more exhaustive analysis, future studies can be dedicated to investigating the alignment between the six aforementioned relationships quantitatively.

Data analysis revealed that tasks and structure components are both institutional by nature, thereby can be considered as the institution element. From another part, Fuenfschilling and Truffers' framework also introduces the institution element accompanied by actors and technology as the other STS elements. In this vein, our results can be revisited by the consolidation of structure and tasks to the institution. Consequently, it can be implied that technology, actors, institutions, and the interactions among them influence the overall performance of IoT development as a STS.

According to the results, IoT is developed through a close collaboration among the key stakeholders (government, industry and entrepreneurs) to integrate the institutional and technological issues. Given the socio-technical framework established, this study interprets the IoT development as a component of an ecosystem consisting of a network of technology, government, industry, markets, users and society.

Furthermore, our analysis indicated that the development and diffusion of IoT, as an emerging technology, is highly influenced by redefining the core concepts of legal, social, cultural, technological and market-oriented issues. Not surprisingly, within that diversified range of socio-technical issues, the government, industry, entrepreneurs and customers (as actors) are able to behave purposefully. More importantly, by analyzing issues that contributed to the development of IoT, we revealed how institutions element play a mediating role regarding the IoT evolution. In this regard, it should be noted that the components mapped onto the institutions element were identified pertinent to both the social and technical subsystems of an STS. Thus, this means that institutions element plays a central role in the IoT development.

While the current condition of Iranian IoT development may incrementally assure the technology-oriented requirements, the institutional side is not as simple as the technological side. In terms of policy, the findings implied that serious regulatory and legal changes should be made in defining the future infrastructure and standard more transparently by which IoT will be embedded in that infrastructure effectively. To achieve this, all components should be considered comprehensively to ensure that future tools, technologies, and policies adequately meet the needs of all users and stakeholders (Kshetri, 2017).

Similar to other studies, this research suffers from some limitations implying that there is still a room for improvement. The limitations of this study are twofolds. First, this research does not claim that its findings are universal because its access to appropriate resources was limited to those participants that voluntarily had attended to this research. Second, although a number of issues are discussed, this paper does not present an exhaustive work on analyzing the sophisticated interactions among the social, and technical subsystems toward the IoT development. It should be highlighted that as the distinction between social and technical subsystems is often opaque, the interaction between technological artifacts and social entities is not analyzed obviously (Shin, 2014). Thus, to reach a more transparent perception of the interactions, it would be worthwhile for future research to investigate the technological change associated with evolving IoT.

Given the fact that STS can be described as a dynamic system, it is crucial to uncover the vague queries about how the technology and institutions elements become restructured, and what role actors play in such processes when an emerging technology is being developed (Fuenfschilling and Truffer, 2016). To achieve this, the present study has made a useful starting point. Nonetheless, this area undoubtedly deserves further research.

In addition to the mentioned future research directions, other areas still merit further discussion and may be assessed by both academia and government. Future research on how to balance and maintain the synergetic relationship among the universities, startup firms and policymakers involving in the IoT development are still required. As the final suggestion, applying a multiple levels perspective would be a nested hierarchy to describe dynamic interactions among technology, institutions, and actors.

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