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Affordances and constraints processes of smart service systems: Insights from the case of seaport security in Ghana

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ABSTRACT

Although smart service systems have received increasing attention in information systems research, their affordances and constraints processes are less studied. In this study, we draw on interpretive case study methodology and technology affordances and constraints theory to investigate a smart service system use for seaport security in Ghana. With insights from the case of Ghana, we introduce an affordance constraints process as a framework to complement the existing affordance actualisation process framework in information systems. Thus, this study contributes to affordance theory with a new constraints process. The study's findings show that smart service systems for seaport security afford autonomous access control, real-time security monitoring, and autonomous data capturing for analytics and reporting. However, such affordances can be constrained by power and internet outages, limited storage capacity, and device breakdowns. From these findings, we discuss implications for theory, research, and practice as well as limitations and directions for future research.

1. Introduction

Recent technological advances in industry and society have been characterised by smart technologies (Nyberg, 2018). As a result, the world is said to be approaching an era of smart everything (Medina-Borja, 2015). Generally, smart technologies are information technology (IT) devices equipped with sensors, actuators, and wireless connectivity (Beverungen, Matzner, & Janiesch, 2017). With machine intelligence, they have capabilities for awareness, monitoring, communication, and interaction with objects and people (Allmendinger & Lombreglia, 2005; Boukhris & Fritzsche, 2019). With such capabilities, objects such as electricity meters, refrigerators, and washing machines have become smart (Beverungen et al., 2017).

Smart technologies enable smart service systems, which are configurations of IT artefacts, physical objects, environments, and people for value co-creation (Lim & Maglio, 2018, 2019). In recent years, such systems have become useful in various sectors (Demirkan et al., 2015). In the energy sector, smart service systems have become useful for efficiency in energy generation, distribution and consumption (Nyberg, 2018). In healthcare, they have become useful for homecare (Wessel et al., 2019) and for supporting people with disabilities (Wessel et al., 2019). With smart service systems, society is also experiencing modernization and improvement through smart cities (Ismagilova, Hughes, Dwivedi, & Raman, 2019) as well as smart working, living and organizing (Elbanna, Dwivedi, Bunker, & Wastell, 2020).

Research on smart services systems cuts across multiple disciplines such as service science (Beverungen, Müller, Matzner, & Brocke, 2019; Barile & Polese, 2010; Lim & Maglio, 2018), computer science (Georgakopoulos & Jayaraman, 2016) as well as manufacturing, logistics, energy, mobility and health (Beverungen et al., 2017, 2019). In recent years, smart services system research has also attracted interest in information systems (IS) (Beverungen et al., 2017, 2019; Wessel et al., 2019) in areas such as smart cities and government (Ismagiloiva, Hughes, & Rana, 2019; Ismagilova et al., 2019; Rana et al., 2019); smart environment (Geirbo, 2017; Koo, Chung, & Nam, 2015); smart homecare (Wessel et al., 2019); smart working, living and organizing (Elbanna et al., 2020; Papagiannidis & Marikyan, 2020) as well as smart tourism and hospitality (Arenas, Goh, & Urueña, 2019; Neuhofer, Buhalis, & Ladkin, 2015).

One emerging area on smart service systems in IS research is seaport (Heilig & Voß, 2017; Heilig, Schwarze, & Voß, 2017). Traditional seaport research focused mainly on inter-organisational information systems (IOISs) to support port community interactions (Heilig & Voß, 2017; Heilig, Schwarze et al., 2017; Rodon, Pastor, Sesé, & Christiaanse, 2008). For example, Rodon et al. (2008) applied actor-network theory to investigate IOIS in port communities. Nevertheless, following advances

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in smart ITs, smart service systems have begun to attract research in IS (Cimino et al., 2017; Heilig, Schwarze et al., 2017).

However, extant studies have mainly been literature reviews and conceptual papers. Studies based on theory-driven analysis remain limited. The situation could be attributed to the novel and emerging nature of the phenomenon. Therefore, the need exists for IS research based on theoretical analysis to provide in-depth explanation and understanding of smart service systems for seaport. Moreover, the extant literature review and conceptual studies have focused on national single windows, IOSs, vessel traffic systems, terminal operating systems, gate appointment systems, automated gate and yard systems, road and traffic control systems and port hinterland intermodal systems (Heilig & Voß, 2017). Thus, knowledge gap exists on theory-driven research on smart service system for port security. One area that is yet to receive IS research attention is smart service systems affordances for seaport security

Following this research gap, the purpose of this study is to understand affordances and constraints processes of smart service systems for seaport security. The topic on seaport security is of significant research interest for two reasons: (1) seaports are prone to various physical security challenges such as unauthorised access, container and cargo theft, stowaways and terrorism; (2) digital and physical capabilities of smart technologies present opportunities for seaports to better address their physical security threats. Hence, the need exists for empirical IS research to understand situated uses and constraints of smart service systems for seaport security.

Hence, the research question for this study is: how do affordances of smart service systems for seaport security become actualised and constrained? By addressing this question, we can contribute to a better understanding of smart service systems enablement and constraints. To address the research question, the study employed interpretive case study as the methodology (Klein & Myers, 1999; Walsham, 1995, 2006) and technology affordances and constraints theory (Majchrzak & Markus, 2013) as analytical lens to investigate the use of smart service systems for security in Tema Port of Ghana. This port was chosen because it had deployed and used smart service systems for its operations, including physical security to prevent possible threats from the landside, seaside and inside of the seaport.

The rest of the paper is organised as follows. Section two reviews the literature on smart technologies and service systems in general and on seaports. Section three presents technology affordances and constraints theory as the analytical lens of the study. Section four describes the research methodology. Section five presents the case description, which is followed by the case analysis in section six. Section seven discusses the research findings and the implications for theory and research as well as for practice. Finally, section eight presents the conclusion with the study's contribution and recommendations for future research.

2. Literature review

2.1. Smart technologies and service systems

Smart technologies are designed with sensing, configuration, and decision making capabilities for security monitoring, autonomous control, and interaction with other objects (Maglio & Lim, 2016; Wessel et al., 2019). For example, as a smart technology, a global positioning system (GPS) can sense, monitor, and control locations of objects (Wessel et al., 2019). Smart technologies have both digital and physical properties to sense, monitor, analyse, and control physical and digital environments (Beverungen et al., 2017). When combined with internet of things (IoTs), smart technologies enable physical objects for digital services (Paukstadt, Eicker, & Eicker, 2019).

Smart technologies are associated with intelligence (Allmendinger & Lombreglia, 2005; Boukhris & Fritzsche, 2019), a capability previously attributed to humans only (Allmendinger & Lombreglia, 2005). However, with advancements in artificial intelligence (AI), physical objects such as cars and phones have increasingly become smart (Lim & Maglio, 2019; Martin, Hirt, & Kühl, 2019). As a result, smart technologies can monitor, make decision and perform activities without human interventions (Paukstadt et al., 2019; Porter & Heppelmann, 2015). However, unlike natural human intelligence, AI for smart technologies rely on machine intelligence (Allmendinger & Lombreglia, 2005).

Smart technologies serve as infrastructure for smart service systems. As a result, smart service systems are configurations of smart technologies, information technologies, physical objects, environments, processes, and people that together create value for users (Beverungen et al., 2019; Paukstadt et al., 2019). Thus, while traditional service systems rely on people and physical processes (Vargo & Lusch, 2008), smart service systems rely on smart technologies to provide services for stakeholders (Beverungen et al., 2017). Therefore, being service focused, smart service systems are not only technical but socio-technical in relation to value-creation (Ismagilova et al., 2019; Lim & Maglio, 2019). Thus, IS research on smart service systems should not only focus on smart technologies but on processes and policies as well (Ismagilova et al., 2019; Singh et al., 2020).

From their literature reviews, Lim and Maglio (2018, 2019) summarise the core attributes of smart service systems as 5Cs: (1) connection between things and people, (2) data collection for context awareness, (3) computation, (4) wireless communication, and (5) value co-creation. With such capabilities, the key functions of smart service systems are monitoring, controlling, optimisation, and autonomous actions (Paukstadt et al., 2019; Porter & Heppelmann, 2015). Monitoring involves data sensing and environmental awareness of conditions and state of objects, people and spaces, including alerts and notifications for changes (Porter & Heppelmann, 2015). Controlling involves self-manipulation and remote manipulation of objects (Beverungen et al., 2017). Optimisation involves using information from smart technologies for appropriate decisions in a particular context (Paukstadt et al., 2019). Autonomous capabilities involve application of machine intelligence and self-operation without human intervention (Paukstadt et al., 2019; Porter & Heppelmann, 2015). With these functionalities, smart service systems promote analysis and evaluation of big data (Ismagilova et al., 2019; Klötzer & Pflaum, 2015) to support intelligent decisions and planning (Sadiku, Wang, Cui, & Musa, 2017).

The use of smart service systems offers several benefits to users (Beverungen et al., 2019). Smart service systems enable actors and objects to capture, retrieve and analyse data on changing situations and environments (Beverungen et al., 2019; Ismagilova et al., 2019). Another benefit is automated integration of physical and digital components to capture and analyse data to support decision making (Klotzer, Weibenborn, & Pflaum, 2017). In addition, smart service systems enable remote and real-time machine-to-machine (e.g. IoT) and machine-to-human connectivity (Shim, Avital, Dennis, Rossi, & Sørensen, 2019). They also enable remote control of objects without the need for physical presence (Beverungen et al., 2019).

However, there are challenges with using smart services (Zhao & White, 2017). One such challenge is incompatibility of components for system integration due to lack of global standards of technologies by different organisations (Rana et al., 2019; Zhou, Liu, & Zhou, 2015). Another challenge is security threats (Mahmoud, Hamdan, & Baroudi, 2019) as the combination of physical and digital elements exposes smart service systems to security risks. Also, smart technologies increase risks associated with personal data privacy especially as related to smart cities and citizen data collection and management (Ismagilova et al., 2019; Rana et al., 2019). Moreover, the inability to re-charge battery-powered devices can pose a challenge (Wessel et al., 2019). For example, Wessel et al. (2019) identified the need for frequent charging of batteries as a challenge for smart technologies to support people with disabilities.

The above discussion demonstrates the increasing interest of smart service systems in IS research. However, given that the extant studies have largely been conceptual and literature reviews without theoretical bases, the need exists for theory-driven empirical studies to provide in-depth understanding of smart service systems in specific domains such as seaports.

2.2. Smart service systems in seaports

The area of seaports has attracted some research attention in IS. Earlier studies focused on inter-organisational information systems (IOIS) for port communities (Rodon et al., 2008). Following smart technologies, recent studies in the form of conceptual discussions and literature reviews (e.g. Heilig & Voß, 2017; Heilig, Schwarze et al., 2017; Heilig, Voß, & Lalla-Ruiz, 2017) have focused on smart services systems in seaports. Such systems use GPS to detect and track locations of objects such as vessels, containers, cranes and trucks. In addition, they use optical character recognition (OCR) for automatic identification of containers and trucks at loading yards and terminal gates. The use of OCR reduces errors in identification of containers, trucks, and cranes. It also helps to reduce congestion in and around seaports.

Seaports also use EDIs to migrate paper-based to paperless process (Wrigley, Wagenaar, & Clarke, 1994) by sharing documents such as bill of lading and packing slips in electronic formats (Heilig, Voß et al., 2017; Shi, Tao, & Voß, 2011). Thus, EDIs enable seaports to improve coordination, collaboration and communication through digital communication. Radio frequency identification (RFID) is another smart technology used by seaports to automate data collection as well as verification and access control of trucks and containers (Shi et al., 2011). For instance, the Port of Seattle used RFID tags on trucks and containers to automatically identify and track them (Heilig & Voß, 2017). Other smart technologies that work with RFID in seaports are real-time location systems, mobile devices, and wireless sensor networks. By combining such technologies, seaports can automate and digitalize coordination among trucks, cranes, and containers to capture and transmit data for operations and analysis (Heilig & Voß, 2017).

Heilig and Voß's (2017) identify the key smart services systems application areas in seaports as national single window, vessel traffic services, terminal operating systems, gate appointment systems, automated gate systems, automated yard system, road and traffic control systems, intelligent transport systems and port hinterland intermodal systems. Thus smart service systems improve seaport operations and services. However, constraints such as incompatible standards and high costs of devices and systems pose challenges to their maximum use (Rieback, Crispo, & Tanenbaum, 2006). In addition, getting all stakeholders to adopt common standards remains key for effective use of smart service systems (Heilig & Voß, 2017).

Following the series of IS reviews and conceptual discussions on smart service systems, the topic has begun to attract IS research in Europe (Acciaro, Renken, & Khadiri, 2020). However, theory-based analysis of their affordances and constraints is yet to receive IS research attention. Hence, this study focuses on affordances and constraints of smart service systems for seaport security from the perspective of affordances and constraints theory.

3. Theoretical foundation: technology affordances and constraints theory

This study draws on and extends the existing affordance actualization process framework with an affordance constraints process framework for our case analysis. Technology affordances and constraints theory (TACT) (Majchrzak & Markus, 2013) was developed to explain enablements of IT artefacts and related constraints (Nambisan, Lyytinen, Majchrzak, & Song, 2017). As an IS and organisational theory, TACT derives from Gibson (1986)'s original affordance theory developed in ecological psychology, which focused on action possibilities that physical environments present to animals. For instance, how a flat rigid surface affords standing or walking to a four-legged animal (Hartson, 2003). To acknowledge the constraints dimensions of IT use, Majchrzak and Markus' (2013) TACT extended Gibson's affordance concept with constraint element for IS and organisational research.

The core concepts of TACT are technology affordance, actor, and technology constraints (Majchrzak & Markus, 2013). First, technology affordances are action possibilities that ITs present to actors. Second, actors are individuals or groups who can perceive and use IT artefacts towards achieving organisational goals. Finally, technology constraints are the ways by which affordances are constrained from achieving intended organisational goals. In this study, technology affordances are the action possibilities that smart service systems provide for achieving seaport security goals. Actors are people who interact with systems to achieve such goals. Constraints are factors that prevent affordances from occurring.

The fundamental principle of TACT is that affordances are relational and therefore emerge from human-technology interactions (Wu, Zhang, Tian, Wang, & Hua, 2020). Thus, affordances are not properties of IT artefacts or humans alone but emerge from their interactions (Majchrzak & Markus, 2013). As already noted, the relational principle is considered useful for addressing problems of technical and social determinism in IS research (Fayard & Weeks, 2014; Thapa & Sein, 2018).

Affordance theories have attracted significant attention in IS research. In recent years, it has been found useful for studying technology-human interactions (Wu et al., 2020) to overcome technological or social determinism (Thapa & Sein, 2018). However, it remains emergent as it continues to be adapted and extended alongside technological advancements. For instance, Wu et al. (2020) extended it to study cloud computing as an emerging IT field. It has also been adapted for other IS domains such as smart green IT (Koo et al., 2015) and work mobility (Nelson, Jarrahi, & Thomson, 2017).

Moreover, initial application of affordance theory focused on action possibilities as factors. However, recent extensions have resulted in the emergence of affordance actualisation as a process (Strong et al., 2014; Thapa & Sein, 2018; Wang, Wang, & Tang, 2018) to explain the temporal dimension of affordances. The affordance actualization process entails perception, actualization and effects. Fig. 1 shows results of the perception, actualisation and effects phases of the process.

Perceived affordances are action possibilities that actors can notice (Thapa & Sein, 2018). Actualised affordances are actions that emerge from actors interactions with information technologies (Strong et al., 2014). Affordance effects are the outcome of the actualized affordances. The affordance actualization process has attracted much interest in IS research (Strong et al., 2014; e.g. Thapa & Sein, 2018). However, its key limitation is the failure to account for constraints, hence the need for its extension to include constraints.

Following the dynamic nature of affordance theory as driven by technological advances and the constraints notion of TACT, this study proposes a constraints process as an extension of the limited actualisation process. This extension is important because affordances are subject to constraints (Majchrzak & Markus, 2013), which may prevent them from achieving intended organisational goals. Fig. 2 shows the proposed constraints process as a complement to the existing actualisation process.

Perceived constraints are factors that limit perceiving affordances. Actualised constraints are factors that prevent perceived affordances from being actualised, while constraints effects are the results of actualised constraints.

We drew on TACT as a theoretical foundation for this study for two reasons. First, unlike the traditional affordance theory which focuses on actions, TACT offers a balanced perspective of both actions and constraints. Also, from its relational principle, TACT promotes a socio-technical perspective by viewing affordance as a relation between social actors and technologies. As a result, it avoids the problem of technical or social determinism in IS research (Orlikowski & Scott, 2008; Sarker, Chatterjee, & Xiao, 2013). In line with interpretive research tradition, our intention was not to test or evaluate the theory, but use it as a sensitizing lens to understand the phenomenon from a particular theoretical perspective (Klein & Myers, 1999; Walsham & Barrett, 2004).

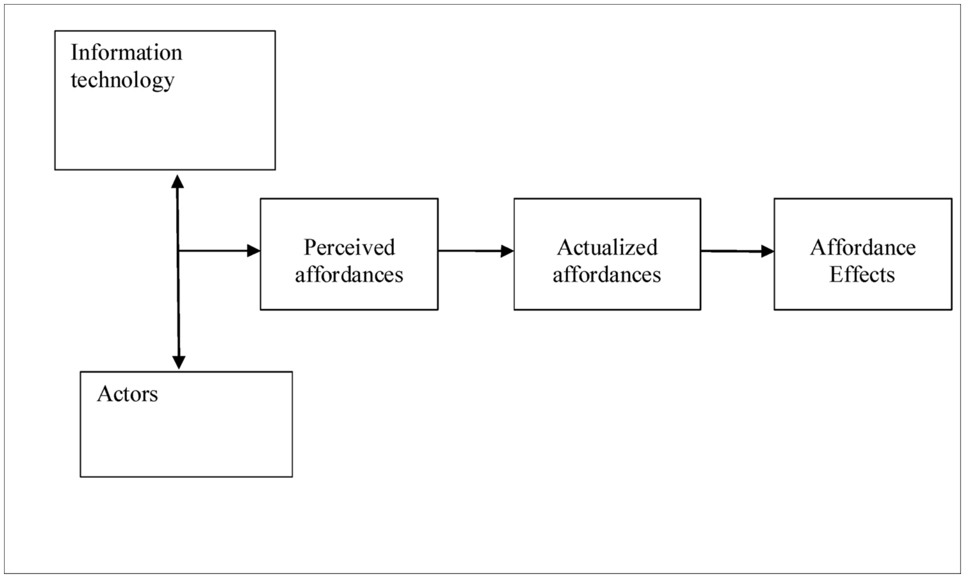

Fig. 1. Affordance actualization process [adapted from Strong et al. (2014), Thapa and Sein (2018) and Wang et al. (2018)].

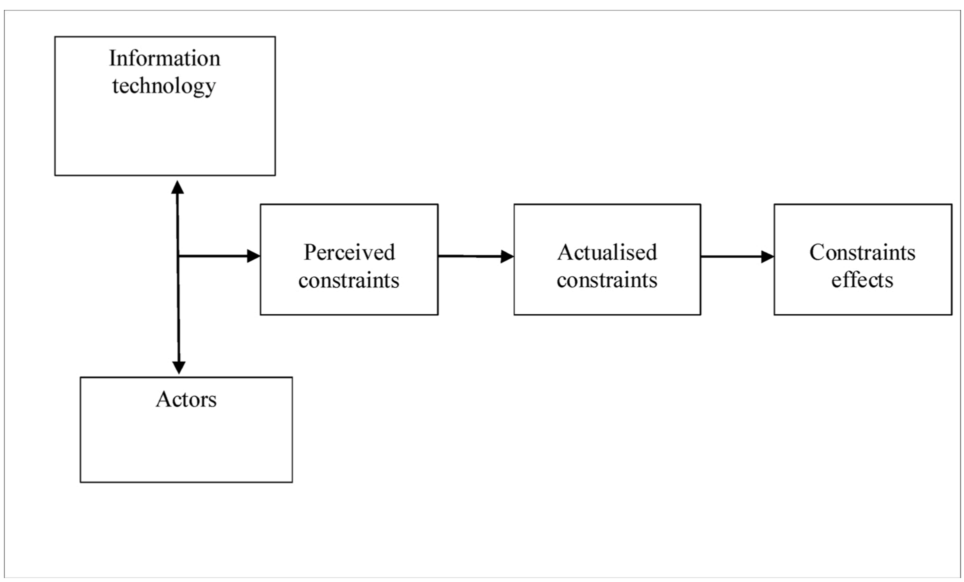

Fig. 2. Affordance constraints process.

In Section 6 of this study, we draw on the newly introduced affordance constraints process and the existing affordance actualisation process as combined theoretical lenses for the case analysis.

4. Methodology

We followed an interpretive case study methodology (Klein & Myers, 1999; Walsham, 1995, 2006) to understand the context, introduction, and use of the smart service systems for seaport security in the Tema Port of Ghana. Given that interpretive case studies follow subjective ontology and epistemology (Myers, 2013; Orlikowski & Baroudi, 1991), we considered this study's phenomenon and the process as socially constructed and therefore subjective rather than objective.

4.1. Data collection

Data collection occurred over a two-year period from 2017 to 2019. In line with the interpretive case study tradition (Walsham, 2006), we gathered data on the smart service systems use from multiple sources, namely interviews, documents, observations and websites. An interview guide was used to collect data from participants selected through purposive sampling (Patton, 2015) based on their knowledge, interactions and experience with the smart service system in Tema Port. Questions on the interview guide focused on expectations, uses, constraints, and effects of the system. In all, 56 participants were interviewed as follows: 6 security officers, 5 security managers, 4 port directors, 8 terminal operators, 6 importers, 7 exporters, 8 IT officers, 5 cargo track drivers and 7 shipping agents.

On average, each interview lasted between 45 min and 1 h, was audio-recorded subject to informed consent of interviewees, and subsequently transcribed for more detailed analysis. In situations where interviewees opted out of audio recording, the researchers took notes and subsequently transcribed the notes for further analysis. Additional data came from organisational documents received from the research participants and those publicly available in newspapers and online sources. Moreover, the researchers had the opportunity to observe and gather data on some uses and processes of the smart service systems, including going through smart entry and exit gates as well as observing activities on smart CCTV displays.

4.2. Data analysis

The analysis was based on hermeneutic circle as the fundamental principle of interpretive research analysis (Klein & Myers, 1999; Sarker, Xiao, Beaulieu, & Lee, 2018; Trauth, Hall, & Jessup, 2000). In interpretive IS research, hermeneutic circle analysis seeks "to piece together people's words, observations, and documents into a coherent picture" (Trauth et al., 2000, p. 54) to provide understanding of a phenomenon as a whole from the understanding of its parts through iterative processes (Cecez-Kecmanovic et al., 2020; Klein & Myers, 1999). In this study, the phenomenon as a whole refers to the smart service system use in Tema Port; the parts are the individual participant's perception, understanding and usage of various components of the system.

In line with the hermeneutic circle, the analysis occurred in two phases: an initial thematic analysis followed by a theory-based analysis. The thematic analysis involved each author's continuous reading and analysis of the gathered data (interview transcripts, field notes and documents). This was followed by periodic meetings to discuss emerging findings, address contradictions, and integrate the individual understanding as parts into an integrated understanding of as the whole. Themes that emerged from the thematic analysis were to develop the case description as presented in Section 5.

The theory-based analysis was informed by TACT concepts and principles to affordance actualization and constraints processes. From the hermeneutic circle and interpretive perspective, the aim was not to test the theory but use its concepts and principles as a sensitizing lens (Flynn & Gregory, 2004; Klein & Myers, 1999) to make sense of the case description. The process involved mapping relevant concepts and processes of the theory to empirical themes related to affordances and constraints of the smart system from perception to actualization and effects of the smart service system use.

Based on the hermeneutic circle, the two phases of the analysis occurred through iterative processes alongside data collection and analysis. Where necessary, we followed up with interview participants for additional data or verification of emerging findings. The hermeneutic circle analysis continued until a saturation point where we realized that further analysis yielded no new insight (Day, Junglas, & Silva, 2009).

5. Case description

The case organisation is Tema Port in Ghana, which is a seaport located on the West Coast of Africa, along the Atlantic Ocean. Established in 1962 by the government, the port facilitates international trade with the rest of the world. It serves as the hub for imports and exports for Ghana and its neighbouring landlocked countries, including Burkina Faso, Mali, and Niger.

As a seaport, Tema Port is prone to physical security threats such as smuggling, stowaways, trafficking, cargo theft, and terrorism. Therefore, physical security activities of the seaport focus on prevention of unauthorised access of people, trucks, and containers; monitoring for security threats; and data capturing for security analysis and reporting.

Up to 2014, security services at the seaport were mainly manual. However, in 2015, a smart security service system was introduced as part of the port's digitalization project. The sub-sections below describe the manual security era as well as the introduction, uses and challenges of the smart service system.

5.1. The manual security era

During the manual era, port security was physical and driven by personnel in charge of access control and monitoring. From the landside, security personnel focused on preventing unauthorised access and exit of people, trucks, containers, and cargo. Potential port users were required to go through pre-gate registration processes involving completing access requisition forms for approval. A security manager commented on the application form as follows:

> The application form captured port user's details. These included name, date of birth, nationality, address, telephone number, organization and purpose of visit and a passport picture.

Successful applicants were issued with port access identity (ID) cards as permission to enter and exit the port. Unsuccessful applicants were prohibited from doing so. Subsequently, authorised port users were required to wear their ID cards on their neck for identification and access control by gate security personnel and patrol teams.

Access control screening at the gates involved security personnel inspecting ID cards to identify authorised port users for entry and exit and preventing unauthorised persons. The security personnel also used metal detectors on people to search for unauthorised objects such as guns, knives and other weapons. Subsequently, permitted people had to log their details and purpose of visit in a notebook. Another security manager commented on the visitors' logbook as follows:

> The logbook captured visitors name, date and time, ID number, and purpose of visit. It also captured time of exit.

For trucks, containers and cargo, drivers were required to provide the necessary documents for inspection and approval on entry or exit through the port gates. In addition, security personnel would conduct physical inspection for possible smuggling, theft and weapons.

From the seaside, ship crew and passengers were also subjected to physical checks and inspection before entry or exit from the port. In addition, security personnel physically inspected documents and searched containers and cargo for smuggled and authorised items as well as weapons.

For monitoring purposes, patrol teams monitored the yard, container terminals, and cargo terminals and the port environs for potential threats. According to the head of security:

> *Security personnel monitor all port zones, including entrance and exit gates on a 24 -h basis. The patrol team moves around within and outside the port.*

Objects such as concrete walls, barbed wires, and metal fences within and around the port also served as deterrence to unauthorised people.

However, the manual security system had some challenges. The physical processes were laborious and inefficient. Truck drivers and port users complained about congestion and delays at port entry and exit. Manual security checks often caused traffic congestion and frustrations. As noted by a deputy security manager:

> *To exit the port, physical searches are carried out by security persons. Drivers were required to submit documents on cargoes for inspection. The inefficient process often caused traffic and congestions.*

Another challenge was limited access to data for analysis and reporting. It was difficult to track who had entered or exited the port at a point in time. Visitors were not permitted to stay in the port for more than 24 h. The manual tracking however made it difficult to enforce this rule. Also, tracking stowaways and overstaying by port visitors was difficult. Also, reconciling data between different entry and exit points to check overstaying was problematic.

In addition, manual recording of events made access to information for security planning and management difficult. Thus, management did not have access to reliable data for planning and decision making. Moreover, the manual system created opportunities for some security personnel to connive with unauthorized port users. Yet, in the absence of information on such corrupt practices, getting the evidence on this was difficult.

5.2. Introducing the smart security system

In 2015, management of the port decided to introduce a smart security system to address challenges with the manual security system. After interacting with potential IT consultants, the management perceived smart technology as the opportunity for improving the security situation. They decided to replace the security personnel and physical processes with a smart service system for access control and security monitoring.

However, management also perceived some challenges, such as high project cost and inadequate funds. From experience, they were concerned about delays in getting approval and funds from the government. Another perceived hurdle was undue delays in government procurement processes. Fortunately, they succeeded in convincing the government to approve funds for the project, notwithstanding the high costs. They subsequently contracted the consultant to implement the smart security system. However, due to delays in procurement, the project start delayed.

After a while, the implementation began with installation of a central database and online application platform. A central monitoring facility was setup and equipped with smart CCTV monitors, cameras, and mobile devices for real-time video surveillance. Electric wires with sensors and CCTV cameras were also installed on the fence walls around and within the port. Automatic gating systems, turnstiles and biometric readers were installed for access control.

Physical gates were replaced with smart gates. RFID and OCR portals were installed at various points. Automatic scanners were also installed to screen trucks, containers and cargo. A senior security officer commented on the smart security setup as follows:

> *As part of modernizing security processes, CCTVs with video recording functionalities have been installed at vantage positions within the seaport perimeters. The devices offer long-range detection and thermal imaging in both sub-sea and extreme conditions. The smart CCTVs are connected to the central monitoring room where personnel monitor footages on large screens*

In addition, smart CCTV cameras and monitors were installed to replace the security monitoring teams. At the same time, patrol boats were also equipped with smart CCTV cameras and monitors, OCR cameras and wireless connectivity to detect and deter unauthorised access and exit by vessels.

Finally, analytics software was installed to analyse security data on movements and activities of people and trucks within and around the port. The intention was to replace the existing manual data capturing system to make security-related data and information available to management for informed decision making.

5.3. Smart security uses and challenges

Actual use of the smart security system in Tema Port began in 2017. From the landside, new pre-gate security check processes require potential users to apply online for access permit by providing personal details and uploading copies of their national IDs. After submission, the online system sends an e-mail and a text message to the applicant with an appointment schedule for biometric registration. Successful applicants receive biometric ID cards as access permits.

At a smart gate, visitors biometrically authenticate themselves through finger scanning. The smart turnstile systems screen them to detect any metals and weapons. In case of any detection, the turnstile rings an alarm and stops for further security checks. An IT Manager at the port commented on the benefits of the new access control system as follows:

> *The new system helps to reduce congestion because it prevents authorised access. Also, people are not allowed to stay in the port for more than 24 h; the system tracks those that have exited, those still in the port and stowaways.*

For vehicles, pre-gate checks require online application and upload of vehicle details (plate and chassis numbers) as well as driver and owner details including email addresses and mobile number. The online platform schedules appointments for physical examination and informs drivers through e-mails and text messages. If successful, an RFID sticker is affixed on the windscreen.

At the smart gate, vehicles are automatically identified by the RFID system and permitted to enter or exit. Drivers biometrically authenticate themselves through finger scanning. A truck driver explained the new access process as follows:

> *Once the vehicle and the driver are recognized, the boom barrier will automatically open allowing the truck to go to the next stage.*

At OCR portals, smart readers automatically identify vehicles, direct drivers, and transmit data without human intervention. This process helps to eliminate errors and make the process faster. As vehicles pass through the portal, OCR readers and smart cameras capture and transmit information, images and videos check for theft, smuggling and unauthorised cargo.

Inside the yard, RFIDs track locations and movement of vehicles and containers. Smart weighing devices also capture weights of vehicles and containers. On exit, vehicles and containers are tracked by RFID and OCR readers. A customs officer stated that:

> *At the main exit gate, trucks are recognized by RFID readers and the smart gates open for them to exit.*

At the seaside, smart cranes are equipped with RFID and smart cameras to identify and track vessels and containers. Passengers and crew as well as their luggage go through smart security scanners, gates and turnstiles, which capture and transmit related data to the online application database.

However, challenges such as power and internet outages pose problems for the smart service system use. As the system depends on electricity and internet connectivity to function, disruptions or instabilities in their supply render the entire security systems ineffective. Another challenge is limited storage capacity for the volume and frequency of data collected, especially with video recordings from CCTV camera for monitoring. As a result, historical data are periodically deleted to create space for new data. However, this is problematic. As one IT officer noted:

> *deleting such data means that evidence available for security analysis could be compromised.*

Another challenge is frequent breakdown of equipment such as CCTV and RFID cameras. As these devices get exposed to the harsh salty waves and windy environments, they often breakdown from corrosion. Yet, it cost so much to replace such equipment, which is not produced in Ghana. Moreover, faulty devices take too long to replace, thereby hampering the security service. These challenges are worsened by undue delays in government procurement processes as well as lack of maintenance culture in the public sector.

6. Case analysis

Analysis of the case description draws on TACT, the existing affordance actualisation process, and the new affordance constraints process introduced in Section 3. Fig. 3 shows components of the smart service system for the seaport security. The smart technologies are smart gates, smart CCTV, smart cameras, RFIDs, OCRs, centralized database, online applications, and analytics software. The organisational actors are management and users who interact with elements of the system. The security affordances that emerge from interactions between the

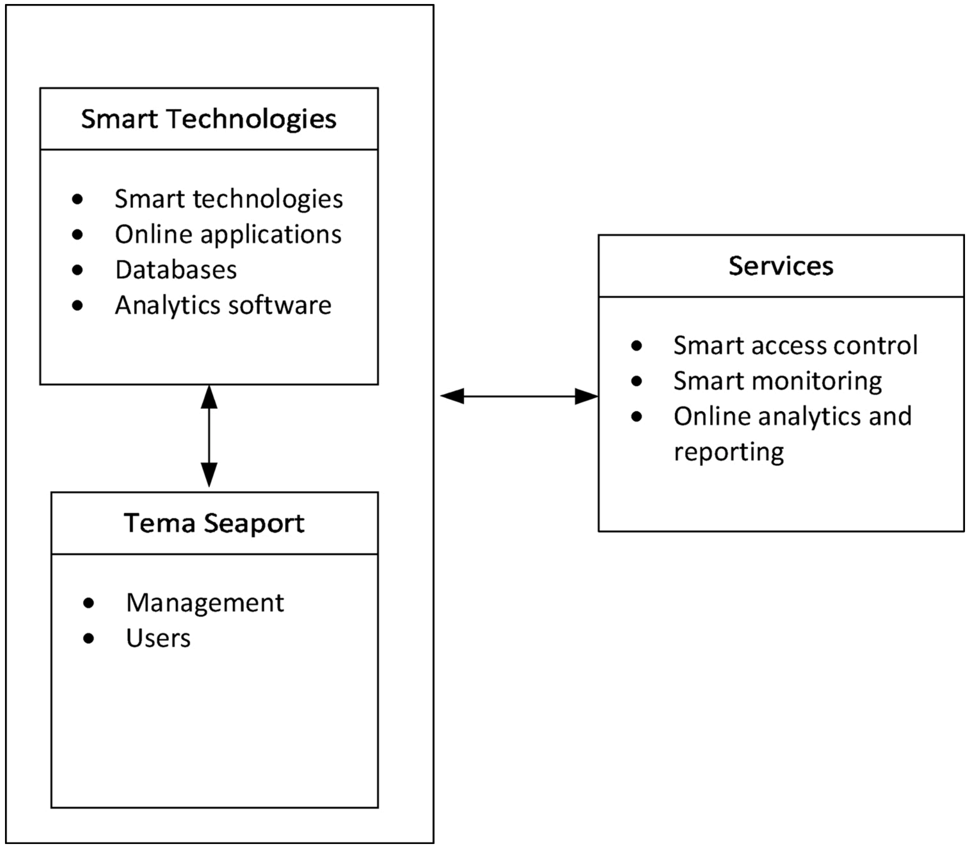

Fig. 3. The smart service system for security services.

technologies and the organisational actors are smart access control, smart monitoring, and online analytics reporting.

The sub-sections below analyse the process of affordance actualisation and constraints of the smart service system.

6.1. *Affordance actualisation process*

From the case description, the security affordance actualisation process involves perception, actualisation, and effects. Fig. 4 shows the three phases as perceived affordances, actualized affordances and affordance effects.

At the perception phase, the port saw the smart service system as an opportunity to replace security personnel with smart technologies in order to automate access control, monitoring, and security data management. It was expected that replacing the physical gate and the security personnel with smart gates would improve access and exit controls, reduce inefficiencies, and minimise congestion. Second, management expected that replacing the security patrol team with smart cameras would improve security monitoring with 24/7 surveillance and capture video data for evidence. Finally, management perceived an opportunity to replace the inefficient paper-based information system with smart service system to generate real-time and archival digital data for analysis and decision making.

At the actualisation phase, the smart service system afforded autonomous access control, autonomous monitoring of the port environment, and autonomous data capturing for analysis and reporting. These processes were actualised by the various smart technologies, namely OCR, smart gate, RFIDs and smart CCTV cameras to automate identification, authorisation and control processes for people, trucks and containers. Moreover, the smart CCTV system enabled automatic monitoring and recording of audio-visual information for analysis. In addition, the smart technologies interacted with the online applications, databases, and analytic tools for automatic data capturing, storage and analysis.

At the effects phase, some positive effects emerged. First, the use of smart security system reduced human effort, improved efficiency, and

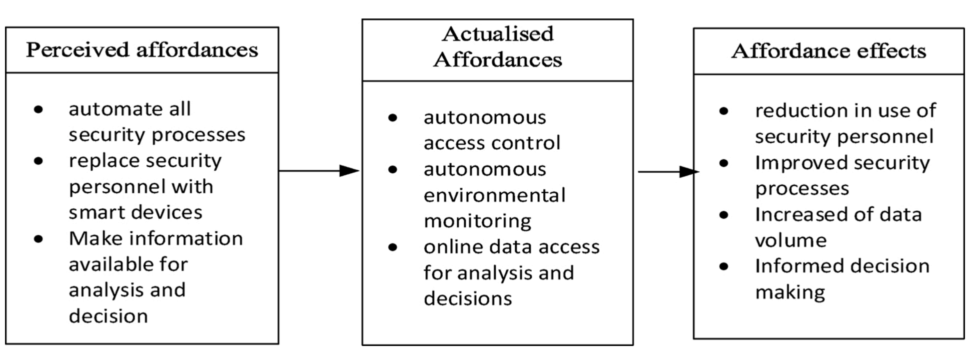

Fig. 4. Affordance actualisation process.

increased availability and access to data and information. For reduced human effort, use of the system led to removal or reduction in human intervention, such as operating physical gates, searching and screening people and trucks, patrolling port yards and container terminals, and booking security incidents. Use of the smart technologies has also reduced congestion outside and inside the port. In addition, access to online and variety of data has improved. During the manual security era, data were recorded in exercise books and management had no readily access to information. With the smart security system, management has readily online access to variety of data including audio, video, image, text and dashboard reports.

6.2. Affordance constraints process

From the case description, the affordance constraints process also involves perception, actualisation, and effects. Fig. 5 shows the three phases as perceived constraints, actualised constraints and constraint effects.

At the perception phase, management perceived high project costs, huge funding requirements and procurement delays as potential constraints for acquiring and implementing the smart service system for security. As the port is a public sector organisation, management was not sure of getting government approval and funding. Beyond funding, management perceived delays in government procurement processes as constraints.

At the actualisation phase, the real constraints were electricity outage, internet outage, limited storage capacity, and salty sea environment. In times of power and internet outages, the smart service systems became dysfunctional, causing the port to revert to the manual security system. Over the years, electricity and internet outages have become a national problem, which is not specific to the seaport. Another actualised constraint was the limited storage capacity for the voluminous data captured from video recording and the RFIDs, OCRs and smart gate devices. Another constraint was frequent breakdowns of externally installed devices such as smart cameras and RFID devices due to the salty sea environment.

At the effects stage, the constraint effects were limited storage capacity, periodic deletion of data, inability to capture data during outages and breakdowns as well as periodic returns to manual security processes. Limited storage capacity and high volumes and variety of captured data resulted in periodic deletion of data to make space for new data. The effect is loss of data for forensic security analysis. The effects of power outages, internet outages and machine breakdowns are the periodic returns to manual security system and the associated challenges. This situation leads to breaks in digital data capturing and the need to import system components, which are not locally produced.

7. Discussion

This section discusses the research findings from the case analysis in response to the research question on how smart service systems for seaport security become actualised and constrained. The discussion focuses on affordance actualisation and constraints processes, implications for theory and research as well as practice, and limitations and directions for future research.

7.1. Affordances and constraints of smart service systems for security

From the case analysis, the main affordances of smart service systems for security in the seaport were autonomous access control, real-time security monitoring, autonomous data capturing, and analytics for dashboard reporting. First, compared to manual security system, use of smart service systems affords improving access control as a benefit. Under the human security era, security personnel managed access control. The effects were delays, traffic congestion, and sometimes connivance between security personnel and unauthorised people to gain access. On the contrary, the migration to the smart service system improved efficiency and effectiveness of the access control service. These findings support existing ones in the literature on the autonomous capability of smart technologies in performing some activities in place of people (Baheti & Gill, 2011; Martin et al., 2019; Porter & Heppelmann, 2015). The findings also demonstrate the various benefits of smart service systems in the extant literature (Heilig & Voß, 2017; Heilig, Voß et al., 2017) in terms of using OCRs, RFIDs, and smart devices for automatic identification of containers, trucks and cargo and the positive outcomes of reducing congestion.

However, the constraint findings also show how the security system had to revert to manual access control during power and internet disruptions. Challenges with smart service systems discussed in the extant literature include security vulnerability (Williams, Basker, & Ward, 2008) and lack of global standards adoption for system compatibility and interoperability (Garstone, 1995; Heilig & Voß, 2017). However, the issue of electricity and internet disruption in organisational environment as a constraint is new. The novelty of this finding can be attributed to the developing country environment in this case, where reliability of internet and energy infrastructure is not guaranteed. Moreover, given maintenance issues in developing countries, organisations using smart technologies need to pay adequate attention to planned maintenance rather than wait for machines to breakdown.

In addition, the use of the smart security system enabled autonomous security monitoring. With the use of smart CCTV cameras and monitors, the port could monitor the inner and outer environments to detect security threats. Previously, the use of security personnel to patrol the environment was found to be ineffective. However, the use of smart cameras not only provided autonomous monitoring but also video recorded ongoing events in real-time. Under the human security era, monitoring of movements and events in and around the port was never recorded. Only security breaches were recorded but on paper. Autonomous monitoring capability of smart service systems is well noted in the extant literature (Lim & Maglio, 2018, 2019). However, finding from this study show how harsh seaport environment can negatively impact the performance of smart devices for security monitoring.

Another finding relates to autonomous data capturing for analytics and reporting. Under the human security era, the port used paper

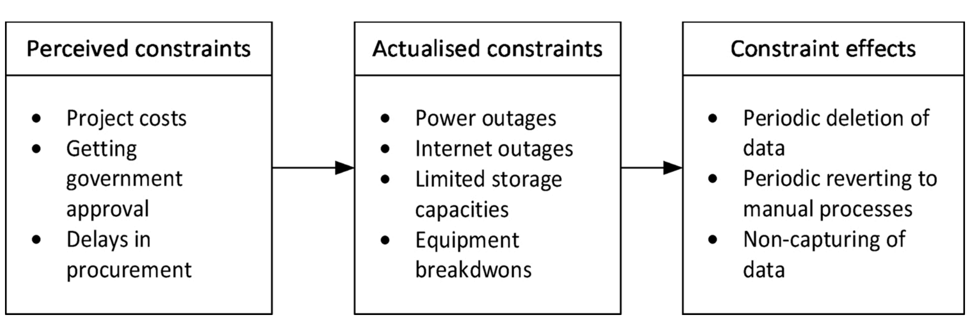

Fig. 5. Affordance constraints process.

documents to log security events and activities. As a result, management had no access to information for strategic assessment and decisions. However, the use of smart technologies afforded autonomous data capturing and transmission to make information available for analytics and management reporting. Again, the extant literature has noted capabilities of smart service systems to automate big data capturing and transmission (Lim & Maglio, 2019) for analytics and reporting (Maglio & Lim, 2016; Medina-Borja, 2015). However, the negative finding in this study on the need to periodically delete data due to limited storage capacity is new. This can be attributed to the generally limited ICT infrastructure in developing country environments. Nevertheless, cloud storage infrastructure presents opportunities for developing country organisation to address such limitations.

7.2. Implications for theory and research

This study comes as the first to apply affordances and constraints theory (TACT) to smart service systems research, which has largely been based on conceptual studies and literature reviews. The findings from this study provide two implications for theory and research: (1) the need to extend the existing human-technology affordances to include technology-to-technology affordances; (2) the need to complement the existing affordance actualisation process with a constraint process.

On technology-to-technology affordance, this study demonstrates situations of autonomous, agential interactions between smart technologies without human interventions. In relation to autonomous access control, the study demonstrates how technologies such as smart gates, OCR and RFID could interact on their own to identify and permit authorised entities to enter or exit the port without human intervention. In addition, autonomous interactions between these technologies could prevent unauthorised access. Also, such autonomous interactions could capture and transmit data for analysis and reporting without the need for human interaction. Similarly, autonomous interactions between RFID readers and tags could track and report on the locations and movement of objects such as trucks and containers.

Earlier conceptualisations of affordances mainly focused on affordance as emergent from technology-human relations (King & Torkzadeh, 2016; Leonardi, 2011, 2013; Volkoff & Strong, 2013). However, in recent years, smart service systems are gaining more autonomous capability through internet-of-things (Paukstadt et al., 2019; Porter & Heppelmann, 2015) to perform actions and interactions without human support (Beverungen et al., 2019; Paukstadt et al., 2019). The findings from this study show the need for IS studies on smart service systems to go beyond technology-human affordances to include technology-technology affordances and constraints as in the case of how smart devices can autonomously interact to act without human intervention.

The implication for this finding is that affordances and constraints can occur not only between technologies and human agents but also between technologies. Therefore, the proposition from this finding is that with the increasing use of internet-of-things in organisational and social environments, IS research on affordances needs to extend the existing notion of technology-human affordance to include technology-to-technology affordance in autonomous systems environment. Thus, future studies can explore and theorize the nature of technology-to-technology affordances as a complement to technology-human affordances.

This study also demonstrates the need to extend and complement the existing affordance actualisation process with an affordance constraints process framework for better understanding and explanation of smart technology uses in physical environments. Existing conceptualisation and applications of affordance actualisation processes (Sein, Thapa, Hatakka, & Sæbø, 2019; Thapa & Sein, 2018; e.g. Wang et al., 2018) has focused mainly on perception, use and effects of human-technology interactions without much attention to related constraints from their environment.

With insights from this study, the affordance constraints process framework was introduced to complement the existing affordance actualisation process. In reality, technology affordances can be constrained by their environments (Strong et al., 2014). The implications of this theoretical findings are that: (1) actors do not only perceive technologies with action possibilities but also perceive potential constraints; (2) actualized affordances are shaped by actualised constraints; (3) intended affordance effects are subject to constraints effects, which can result in unintended consequences.

Following these implications, a related proposition is that: affordance actualisation process provides a partial view of technology affordances and constraints. Therefore, there is the need to complement affordance actualisation process with affordance constraints process for a more comprehensive and balanced theoretical framework of IS research on technology affordances.

7.3. Implications for practice

The findings from this study provide some practical implications for the use of smart service systems for seaport security management and practice. From the findings, smart service systems have capabilities to improve seaport security through automated access control, monitoring, and analytics. However, such capabilities can be constrained by inadequate storage capacity to meet the volume and variety of big data that can emerge, harsh seaport environment, and related equipment breakdowns, as well as internet and power interruptions, particularly in the developing world where such services are not always reliable. Following these constraints, the key practical implications are as follows.

First, to address the huge storage space demand for big data from smarts service systems use, management can adopt cloud computing solutions. In the case of Tema Port, the failure of management to provide adequate storage capacity for big data necessitated periodic deletion of historical data to make room for newly captured data. The situation implies that seaports using smart service systems can deploy cloud storage infrastructure to accommodate increasing volume and variety of audio, video, image and textual data. Cloud computing has been identified as a solution for storing and processing voluminous data in smart system environments (Ismagilova et al., 2019; Singh et al., 2020). With cloud infrastructure, storage capacity can be increased on demand to prevent the need for deleting historical data, thereby retaining such data for trend and pattern analytics.

Second, to address the problem of harsh seaport environment and machine breakdowns, port management need to procure robust smart technology artefacts as well as establish and enforce continuous risk analysis and preventive maintenance practices. Given the negative effects that the salty seaport environment can have on smart technology components to cause breakdowns, seaport management need to procure robust technology components that can withstand harsh sea environments. It is expected that using appropriate and robust rather than ordinary components can prevent such breakdowns and avoid the need to return to the inefficient physical security system. In addition, instituting robust risks assessments and preventive maintenance practices will identify potential technical faults that can be addressed before the breakdowns. Such practices will also prevent the need to return to physical security systems.

Finally, to maximize the benefits from smart service systems, management need to address internet and power outage problems in developing country contexts. Providing reliable electricity and internet services will ensure effective and efficient smart service system operations. One way to solve the problem is to provide independent power source or reliable backup power supply beyond the national grid. Such a backup power should be based on smart technology to start automatically anytime the national power grid goes down. In addition, the experience from Tema Port implies that for a successful smart service system implementation, management and IT professionals need to look beyond functional requirements and pay equal attention to broader infrastructural requirements such as electricity and the internet.

7.4. Limitations and future research directions

Our study has some limitations. First, because we relied on a single case study in one developing country, our findings are limited to situated experiences of a single seaport in a resource constrained environment. To address this limitation, we expect future research to investigate the phenomenon in other developing and developed country settings. Second, our theoretical approach is based on relational affordance perspective at the technology use phase. Thus, our study did not account for functional affordances at the system design and development phases (Hartson, 2003; Seidel, Recker, & Vom Brocke, 2013). We expect future studies to extend the scope of affordances and constraints to including system design phases.

Third, our affordance and constraints framework is based on a single process design from perception to actualisation to effects. By this, our study fails to account for iterations through feedbacks in the affordance actualisation and constraints processes. Given that an affordance process can be iterative with feedback from outcome to influence perception and actualisation (Strong et al., 2014), future research can extend our single process view to include iterations in affordances and constraints processes. Finally, our empirical observation focused on technology-human interaction affordances. As the findings of the study show, autonomous smart service system can operate without the need for human intervention. Hence, we expect future studies to explore theoretical frameworks for autonomous technology-to-technology or machine-to-machine affordances and constraints in IoT environments.

8. Conclusion

The purpose of this study was to understand affordances and constraints processes of smart service systems for seaport security. From the findings, use of smart service systems for seaport security affords autonomous access control, security monitoring, and data capturing for analytics and reporting. However, such affordances can be constrained by electricity and internet outages, limited storage capacity, as well as device breakdowns due to salty sea environments and lack of maintenance, particularly in developing country and resource constraints environment.

The study contributes to theory and research on smart services systems in IS. First, it draws on insights from the study to introduce an affordance constraints process framework to complement the existing affordance actualisation process framework in IS research. Following this, we argue that the two combined frameworks offer a more balanced and comprehensive theoretical framework for technology affordances research in IS. We also extend the existing notion of technology-human relational affordances to include technology-to-technology affordance for research on IoT and autonomous smart service systems without the need for human interactions.

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