Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 36 (2014) 124 – 130

Procedia Computer Science

Complex Adaptive Systems, Publication 4
Cihan H. Dagli, Editor in Chief
Conference Organized by Missouri University of Science and Technology
2014- Philadelphia, PA

Data Infrastructures for Asset Management Viewed as Complex Adaptive Systems

Paul Brous[ab*], Irene Overtoom[a], Paulien Herder[a], Arie Versluis[b], Marijn Janssen[a]

[a]*Delft University of Technology, Jaffalaan 5, 2628 BX, Delft, The Netherlands*
[b]*Rijkswaterstaat, Derde Werelddreef 1, 2622 HA, Delft, The Netherlands*

Abstract

Data infrastructures represent information about physical reality. As reality changes, data infrastructures might also be subject to change. Researchers have increasingly approached physical infrastructures as being complex adaptive systems (CAS). Although physical infrastructures are often approached as CAS, the underlying data infrastructures hardly are. Studying data infrastructures as CAS has significant implications for our understanding of them. A CAS lens will help us to identify and better understand their key elements and coordination mechanisms for their functioning and dealing with change. Accepting data infrastructures as CASs also means we need to understand the consequences for their development. On the basis of state of the art literature, and an explorative case study of Rijkswaterstaat in the Netherlands, an overview of known data infrastructural elements and the coordination mechanisms connecting them will be presented. The results show that successful development of data infrastructures requires consideration of a wide variety of elements that can be coordinated using various coordination mechanisms. We conclude that a more complete picture of what data infrastructures are and how they can be coordinated is needed.

Peer-review under responsibility of scientific committee of Missouri University of Science and Technology

Keywords: data; infrastructure; complexity; coordination

1. Introduction

Robust, large scale, infrastructure is developed over many years, and decisions regarding this infrastructure have

* Paul Brous. Tel.: +31654352270.
E-mail address: p.a.brous@tudelft.nl.

Peer-review under responsibility of scientific committee of Missouri University of Science and Technology
doi:10.1016/j.procs.2014.09.048

to be made in the midst of a good deal of uncertainty regarding the future[1]. There are many variables that may change over the course of time such as technological advances, political shifts, changing stakeholders, or economic fluctuations. These complexities have only increased over the course of time, greatly increasing the risks involved[1]. More and more, modern organizations tasked with the management of physical infrastructure are relying on data to help them make decisions in order reduce these risks, improve efficiency and achieve their business objectives[2].

Information infrastructures have been defined as a shared, evolving, heterogeneous installed base of information technology (IT) capabilities among a set of user communities based on open and/or standardized interfaces[3]. Information infrastructures offer a shared resource for delivering and using information services in a community. But this definition is insufficient with regards to data infrastructures due to the focus on IT assets and the lack of attention for the content within the systems and the interaction of communities between themselves and with the information infrastructure itself. IT systems enable the automation of data infrastructures just as technological advances enable the development of physical infrastructures. For example, the term "Spatial Data Infrastructure" (SDI) is often used to denote the relevant base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data[4]. The focal point of the SDI concept is facilitating the interaction between data and people. A SDI can therefore be seen as a sociotechnical assembly rather than simply a technical tool[5]. For the purpose of this research we follow the reasoning of spatial data infrastructures and define data infrastructures as being a shared, evolving, heterogeneous, set of resources capable of continuously providing data required by organizations to manage and maintain their physical resources.

The methodology used in this research will be explained in section two. On the basis of state of the art literature and an explorative case study into which elements and coordination mechanisms can be found in present day data infrastructures, an overview of known data infrastructural elements and the coordination mechanisms connecting the elements will be presented in section three. The case under study is Rijkswaterstaat in the Netherlands. Rijkswaterstaat is part of the Dutch Ministry of Infrastructure and the Environment and is responsible for the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands. The results of the literature review and the case study and the potential impact of adopting a CAS lens on data infrastructures will be discussed in section four. The results show that successful development of data infrastructures requires consideration of a wide variety of factors. This implies that a more complete picture of what data infrastructures are and how they can be coordinated is needed. The conclusions will be drawn in section five.

2. Methodology

To determine the elements and coordination mechanisms of data infrastructures we followed two research steps. First the common elements and coordination mechanisms of data infrastructures were identified from a rigorous review of literature. As guiding research linking data infrastructures to CAS we followed Grus et al. (2010)[6]. We then followed an explorative case study research method to identify data infrastructure elements and mechanisms in an organization. The case under study is Rijkswaterstaat in the Netherlands. This includes the main road network, the main waterway network and the main water systems of The Netherlands. The state road network constitutes of three thousand kilometers of highways, one thousand four hundred km of connecting roads, two thousand seven hundred and forty-nine viaducts, thirteen ecoducts, twenty-two tunnels and seven hundred and forty-three bridges. The case study was explorative in method and descriptive in nature. Unstructured interviews were held with managers, subject matter experts, and internal consultants. Internal documentation concerned with the description of the data infrastructure of the Rijkswaterstaat was studied. The pattern-matching technique[7] was used to analyze the case study evidence. The technique was applied in the following way. First the common patterns of elements and coordination mechanisms were listed. These common elements and mechanisms were then compared with the evidence from the case study analysis.

3. Results: Elements of data infrastructures

Using literature and the case study, seven elements were found that will be discussed hereafter. *All these elements influence data infrastructures.*

The first element is *data*, which has long been recognized as a core factor in information systems and has been generally defined as the measure or description of objects or events[8,9]. Data infrastructures necessarily include data. The term "data" is often used in everyday terminology to refer to either raw data or to information[10,11,12]. In fact there is an important difference between the two[9]. Data are facts about objects, subjects or events within or without the organization. These facts generally involve the condition of the object or subject or refer to a transaction involving that object or subject. Data only becomes information once it is given context and presented in a form that people are able to understand.

Although it is clear that a great deal of data is being produced, managed and maintained, asset managers within Rijkswaterstaat observed that they often do not receive the data that they require because the data is produced by (sub)contractors who produce only the data that they themselves require. Also, data that is produced is often "locked" into systems as, for example, logging files. Retrieving the data for objectives other than those originally defined can be difficult and time consuming. At Rijkswaterstaat, data is produced in order to achieve certain goals. It very much depends on the goals of the parties producing the data as to which data is being produced and how.

Data infrastructures also necessarily include *people*. People are seen as a key element[6,13–17] in data infrastructures as people are responsible for the decision making, design, implementation, and use of the data infrastructure. Without people, the data infrastructure would have no function, nor would it evolve. With regards to people, knowledge management is of utmost importance[17]. Local knowledge is often central to the ongoing maintenance of data, particularly in the face of unanticipated and unpredictable changes in local context and practice[17]. Furthermore, people have a direct influence on the role of organizational culture within data infrastructures[5]. De Man (2007) believes that effective data infrastructures are developed and applied around commonly felt needs.

The Rijkswaterstaat employees appear to be the driving force behind the success of their data infrastructure. Despite major reorganizations over the last few years and large budget cuts, Rijkswaterstaat has a culture of "getting things done". Workarounds and quick fixes are often made at a local level in order to ensure that the system continues to function. This means that local knowledge is central to the ongoing maintenance of data within the Rijkswaterstaat.

Technology within data infrastructures is required to manage connected data resources. This technology must support the data process[18]. The general problem of retrieval faced by the data analysts is that a vast quantity of data is available, but the nature, quality, structure, type, and precise location are often not known[4,18,19]. Furthermore, development issues incurred by legacy and heterogeneous systems drive the need for interoperability. Rijkswaterstaat has a well-developed data access network which allows access to users based on open standards. Although it creates and manages its metadata locally, Rijkswaterstaat also makes use of external facilities to publish its data. For example, Rijkswaterstaat uses the National Spatial Data metadata library, National Geo-Register (NGR) to publish and find its spatial data. Other data types are generally stored in specialized systems such as digital libraries for images and digital photography. The metadata for these data types is created, stored and searched within the system itself.

The wide variety of data formats, protocols and data types drive the need for interoperability through standardization. *Standards* are an agreed upon set of rules that are established by an authority[20]. Despite the plethora of standards, many researchers[6,13,20–22] believe that they play an important role in data infrastructures. Their importance lies within their endorsement by authorities, experts that have significant domain knowledge, and who may have conflicting views but have come to a compromise to ratify a standard[20]. The endorsement of standards allows them to be widely implemented, improving interoperability and supporting the data process.

With regards to its data, Rijkswaterstaat has implemented a variety of open standards in order to maintain compliancy to external policies and directives, but they have also implemented de facto, industrial standards where necessary. The implementation of open standards appears to be driven by compliancy constraints, whereas the implementation of industrial standards appears to be driven by performance necessity.

According to Dawes (2010)[23], *policies* reflect societal choices about how data should be handled. Policies reflect strong values attached to data sources and content as well as access to and participation in the marketplace of ideas. By applying principles, an organization treats data as an object of policy, that is, data itself is the subject of policy making[23]. Policy provides broad general guidance and helps to regulate data processes.

The general, overriding policy echoed by all the respondents was that Rijkswaterstaat was required to do "more with less", with "less" meaning fewer personnel and "more" meaning a higher level of production. The response being to ask the private sector to perform more of the operational tasks and to handle the issue of quality through contract management, whereby (sub)contractors are required to demonstrate system quality. But much work is still being done by Rijkswaterstaat personnel. This is more of an informal principle than official policy, as although policy documents do promote use of the private sector for operational tasks, there is always specific mention of maintaining mission critical knowledge and skills within the organization. Rijkswaterstaat is also required to be compliant with external policy such as the required usage and production of base registrations.

A next element is the data management *process*. Within the data management process, knowledge about work processes encompasses knowledge about the key processes within the data management process: collection of raw data, storage and maintenance of data, and user retrieval and manipulation of data[24–26]. Knowledge about work performance is knowledge about producing high-quality data from data production processes.

During the last few years, Rijkswaterstaat has developed into a process organization in which an executive board member is responsible for managing a particular process. The processes are designed to be in the form of a "client/contractor" relationship, in which the regional divisions are the clients and the supporting divisions are the contractors. Rijkswaterstaat has defined a formal information management process, the "Detailed Information Management Process", but this process is relatively new and there does appear to be some discussion as to its validity. It is certainly not yet widely known or yet implemented throughout the organization. Not all Rijkswaterstaat data processes are handled centrally. A large percentage of the data production is handled either by regional departments, or by external contractors or by project organizations. At the moment of writing there did not appear to be a strictly managed policy as to which division was primarily responsible for data production at what time.

According to Khatri & Brown (2010), *data governance* refers to what decisions must be made to ensure effective management and use of data (decision domains) and who makes the decisions (locus of accountability for decision making)[10]. For example, data governance includes establishing who in the organization holds decision rights for determining standards for data quality. In the past, organizations have generally tended to assign accountabilities for data mostly to IT departments[12]. Wende & Otto (2007) believe that organizations have thereby ignored critical organizational issues[12]. With data governance, companies implement corporate-wide accountabilities that encompass professionals from throughout the organization.

The head of the information management process at Rijkswaterstaat is the Chief Information Officer (CIO) who is supported by a Chief Data Officer (CDO) and a Chief Technical Officer (CTO). The CIO is an executive board member, whereas the CDO and the CTO have advisory roles. The CIO has a double role and is also the Managing Director of the "Central Information Management" division (CIM). As such he is responsible for managing both the organizational process and the operational execution of commissions. Although a large percentage of data management is performed by the CIM, Rijkswaterstaat is in the process of placing responsibility for the governance of their data with the "client" executives, but this process is still very much underdeveloped.

4. Coordination mechanisms within data infrastructures

The variety of elements makes their coordination challenging. A distribution network such as a data infrastructure consists of independent parties that perform activities and interact. The activities performed by one party are dependent on activities performed by other parties and on the commitments agreed upon between the parties[2]. The activities in an organizational process can be separated into the activities intended to attain goals and the coordination mechanisms[27]. The term "coordination mechanism" denotes the way interdependencies between activities are managed[28]. Events happening in the physical environment influence the data infrastructure elements. Coordination is necessary to manage the demand and need for data.

4.1.1. Self-organization

Grus et al. (2010) believe that data infrastructures, as CASs, are able to adjust and adapt themselves to both external and internal influences[6]. For example, increasing concurrence in the sector may force a particular company or organization to adapt by changing its organizational model to a more efficient one and systems may change as they learn from experience. The ability of data infrastructures and CASs to develop a new system structure by themselves is a result of their internal constitution and not a result of external management[6,29]. Self-organization is a process in which a system can develop a complex structure from fairly unstructured beginnings[30]. The process occurs under the influence of both the environment and the legacy of the system.

We found a large amount of evidence for self-organization at Rijkswaterstaat. For example, the introduction of a service-oriented architecture has meant that once silo'ed systems now have data dependencies and connections with a large variety of systems and data sources, which has impacted the level of complexity of the system. There does not appear to be any formal coordination mechanism to coordinate these dependencies.

4.1.2. Coordination by feedback

Grus et al. (2010) suggest that data infrastructures should have feedback loop mechanisms which enable the system to use its own output to adjust its inputs and processes[6]. Coordination by feedback, adaptive coordination, involves coordination during the actual execution of organizational activities and is done by monitoring, feedback and control[31].

There appear to be few coordination mechanisms within Rijkswaterstaat which deal with feedback. Rijkswaterstaat has well-developed portfolio management and information management processes, but there is little uniformity between business domains. The level of detail and the subject matter varies widely between year plans. In general, the planning focuses mostly on developing new functionality and pays lip service to general maintenance. Little attention is given to feedback over achieved results.

4.1.3. Coordination by plan: direct supervision; mutual adjustment; standardization

March & Simon (1958) identify coordination by plan, anticipatory coordination, to achieve organization behavior. This involves planning to coordinate activities that have yet to be executed[31]. These coordination mechanisms suggest the prevalence of a form of governance and organizational structure in which direct supervision, as described by Mintzberg (1993), plays a role[32]. Mintzberg (1993) also believes that mutual adjustment and standardization are important organizational coordination mechanisms.

As mentioned, Rijkswaterstaat does have a well-developed portfolio and information management process, despite the lack of standardization. The governance structure means that most development occurs according to yearly plans, although there does appear to be a lot of room for unplanned development. There was some evidence that although structures and processes were in place, there was lack of knowledge of how these processes worked and a shortage of suitably qualified personnel to enforce the plans.

4.1.4. Allocation of resources: contracting

Another way of managing interdependencies between activities is to divide these activities into subtasks that can be performed by specialist agents. Nwana, Lee and Jennings (1996) define this mechanism as contracting[33]. This way, a decentralized structure is formed which consists of functional components. Data infrastructures as CASs mostly take the form of a patchwork of functional components working together. Allocation of resources is a very prominent kind of coordination mechanism, since various resources are needed to perform a task[33,34]. Contracting emphasizes the allocation of human capital and expertise to different tasks.

In 2013, Rijkswaterstaat introduced the concept of contracting as general coordination mechanism throughout the organization. The focus was placed on the client-contractor relationship. This process is as yet underdeveloped, but there is evidence to suggest that an informal contracting mechanism has been widely accepted for some time. As supporting process, information management within Rijkswaterstaat only develops new systems under contract. A good deal of general maintenance does appear to occur without contract.

5. Discussion

The objective of the research was to identify key elements and coordination mechanisms of data infrastructures. In CAS the system is composed of individual entities (agent) that interact with each other and in this way affect the system level. The CAS lens views the relationship between the elements and the emergent properties. The relationships need to be coordinated.

We used two research methods: (1) a literature review, (2) an analysis of a data infrastructure case study. Here we discuss the results of using these two methods in our research. The literature review served several purposes in research. Firstly, it provided us with an overview of the existing body of knowledge, allowing us to analyze where gaps in knowledge or focus occur. Secondly, it provided us with a theoretical foundation for the research topic. It provided definitions for the key concepts and helped develop a broader knowledge base in the research area. Case study research is a widely used qualitative research method in information systems research, and is well suited to understanding the interactions between information technology-related innovations and organizational contexts[35]. Following the advice of Yin (2003), the protocol used in the case study included a variety of data collection instruments. In order to counter the possible influences of bias, multiple research instruments were employed to ensure construct validity through triangulation[7].

Data infrastructures are complex socio-technical systems and their complexity shows in the physical networks, and in the actor networks, as well as the combination of the two[36]. Complexity arises when the dependencies among the elements become important. The behavior of many complex systems arises from the activities of lower-level components. This is the result of a very powerful self-organizing force that can overcome a variety of changes. As CASs data infrastructures consist of relatively stable and simple building blocks[6], elements, that are linked via mutual interactions, coordination mechanisms.

Data infrastructures represent information about physical reality. As reality changes, data infrastructures might also be subject to change. A design solution is therefore required that can accommodate the information needs and requirements of today's world as well as catering for the needs and requirements of an unknown future state.

Although physical infrastructures are often approached as CAS, their underlying data infrastructures hardly are. Studying data infrastructures as CAS has significant implications for our understanding of them. A CAS lens helps us to identify and better understand their key elements and mechanisms for their functioning and dealing with change. Accepting data infrastructures as CASs also means we need to understand the consequences for their development, particularly when there is a dependence on interactions between the elements of the data infrastructures such as when the development of a new dataset is announced. The resulting anticipation can cause major changes in the behavior of the system, even when the anticipated situation does not arise. Because the individual parts of a complex adaptive system are continually revising their rules for interaction, each element is forced to adapt to the changing behavior of the other elements[7]. In this way, data infrastructures, as complex adaptive systems, continue to evolve, and steadily exhibit new forms of emergent behavior.

6. Conclusions

This research provides a new insight into the elements and coordination mechanisms of data infrastructures from the perspective of CASs. By means of case study analysis and consulting experts it was possible to investigate the possibilities of using CAS theory to describe data infrastructures. Data infrastructures are composed of multiple elements, which make them hard to model and difficult to understand. Key elements of data infrastructures are data, people, technology, standards, policy, processes and data governance. These elements are dependent on each other and need to be coordinated. Coordination can be accomplished by mechanisms including self-organization, coordination by feedback, coordination by plan (direct supervision; mutual adjustment; standardization) and contracting for allocation of resources. Our future research focuses on understanding the coordination of data infrastructures from a CAS Lens and we will explore the system-of-systems approach. The fact that a data infrastructure can be viewed as a CAS has implications for various studies regarding data infrastructures, especially with regards to their development. New development strategies, preferably derived from the research on complex systems, should be further investigated with a view to their possible application in the development of data infrastructures. In addition, the in-depth analysis of CAS elements and coordination mechanisms identified and analyzed in this study may lead to a better understanding of data infrastructures.

Acknowledgements

We acknowledge and thank the people of the Rijkswaterstaat who gave of their time and expertise during the

case study research. This research is funded by Rijkswaterstaat.

References

1. P. M. Herder, J. de Joode, A. Ligtvoet, S. Schenk, and P. Taneja, Buying Real Options – Valuing Uncertainty in Infrastructure Planning, Futures, vol. 43, no. 9, pp. 961–969, (2011).
2. M. Janssen, Designing Electronic Intermediaries: an Agent-based Approach for Designing Interorganizational Coordination Mechanisms, Doctoral Thesis, Delft University of Technology, Delft, The Netherlands, (2001).
3. O. Hanseth and K. Lyytinen, Theorizing About the Design of Information Infrastructures: Design Kernel Theories and Principles, Sprouts Work. Pap. Inf. Syst., vol. 4, no. 12, pp. 208–241, (2004).
4. D. D. Nebert, Developing Spatial Data Infrastructures: the SDI Cookbook, GSDI, (2004).
5. E. W. H. de Man, Understanding SDI; Complexity and Institutionalization, Int. J. Geogr. Inf. Sci., vol. 20, no. 3, pp. 329–343, (2006).
6. L. Grus, J. Crompvoets, and A. K. Bregt, Spatial Data Infrastructures as Complex Adaptive Systems, Int. J. Geogr. Inf. Sci., vol. 24, no. 3, pp. 439–463, (2010).
7. R. K. Yin, Case Study Research: Design and Methods. SAGE Publications, (2003).
8. P. Checkland and S. Holwell, Information, Systems and Information Systems: Making Sense of the Field, Wiley, New York, (1997).
9. W. J. Kettinger and Y. Li, The Infological Equation Extended: Towards Conceptual Clarity in the Relationship Between Data, Information and Knowledge, Eur. J. Inf. Syst., vol. 19, no. 4, pp. 409–421, (2010).
10. V. Khatri and C. V. Brown, Designing Data Governance, Commun ACM, vol. 53, no. 1, pp. 148–152, (2010).
11. S. Lin, J. Gao, A. Koronios, and V. Chanana, Developing a Data Quality Framework for Asset Management in Engineering Organisations, Int. J. Inf. Qual., vol. 1, no. 1, pp. 100–126, (2007).
12. K. Wende and B. Otto, A Contingency Approach to Data Governance, Int. Conf. on Information Quality, Cambridge, USA, (2007).
13. A. Rajabifard, M.E.F. Feeney, and I. P. Williamson, Future Directions for SDI Development, Int. J. Appl. Earth Obs. Geoinformation, vol. 4, no. 1, pp. 11–22, (2002).
14. J. M. Anderies, M. A. Janssen, and E. Ostrom, A Framework to Analyze the Robustness of Social-Ecological Systems from an Institutional Perspective, Ecol. Soc., vol. 9, no. 1, (2004).
15. Janssen, M.F.W.H.A., Chun, S.A., and Gil-Garcia, J.R., Building the Next Generation of Digital Government Infrastructures, Feb. (2009).
16. A. Koronios, S. Lin, and J. Gao, A Data Quality Model for Asset Management in Engineering Organisations, Information Quality Conf., Houston, USA, vol. 17, (2005).
17. J. Ure, R. Procter, Y. Lin, M. Hartswood, S. Anderson, S. Lloyd, J. Wardlaw, H. Gonzalez-Velez, and K. Ho, The Development of Data Infrastructures for eHealth: A Socio-Technical Perspective, J. Assoc. Inf. Syst., vol. 10, no. 5, pp. 415–429, (2009).
18. J. J. Thomas, S. Bohn, J. C. Brown, K. Pennock, A. Schur, and J. A. Wise, Information Visualization: Data Infrastructure Architectures, Int. Working Conf. on Scientific and Statistical Database Management, Charlottesville, USA, vol. 7, pp. 2–9, (1994).
19. L. Roberts, L. J. Blanshard, K. K. Van Dam, S. L. Price, L. S. Price, and I. Brown, Providing an Effective Data Infrastructure for the Simulation of Complex Materials, All Hands e-Science Meeting, Nottingham, UK, vol. 5, pp. 101–105, (2006).
20. A. D. Mathew, L. Ma, and D. J. Hargreaves, A Conceptual Data Modelling Methodology for Asset Management Data Warehousing, World Congress for Engineering Asset Management, Beijing, China, vol. 3, pp. 1086–1095, (2008).
21. D. L. Nastasie, A. Koronios, and A. Haider, Integration Through Standards – An Overview of Internal Information Standards for Engineering Asset, Definitions, Concepts and Scope of Engineering Asset Management, vol. 1, London: Springer, pp. 239–258, 2010.
22. S. Rea, J. Pathak, G. Savova, T. A. Oniki, L. Westberg, C. E. Beebe, C. Tao, C. G. Parker, P. J. Haug, S. M. Huff, and C. G. Chute, Building a Robust, Scalable and Standards-driven Infrastructure for Secondary Use of EHR Data: the SHARPn Project, J. Biomed. Inform., vol. 45, no. 4, pp. 763–771, (2012).
23. S. S. Dawes, Stewardship and Usefulness: Policy Principles for Information-based Transparency, Gov. Inf. Q., vol. 27, no. 4, pp. 377–383, (2010).
24. D. M. Strong, Y. W. Lee, and R. Y. Wang, Data Quality in Context, Commun ACM, vol. 40, no. 5, pp. 103–110, (1997).
25. R. Y. Wang, Y. W. Lee, L. L. Pipino, and D. M. Strong, Manage Your Information as a Product, MIT Sloan Management Review, (1998).
26. D. Ballou, S. Madnick, and R. Wang, Special Section: Assuring Information Quality, J. Manag. Inf. Syst., vol. 20, no. 3, pp. 9–11, (2003).
27. K. Crowston, A Coordination Theory Approach to Organizational Process Design, Organ. Sci., vol. 8, no. 2, pp. 157–175, (1997).
28. T. W. Malone and K. Crowston, What is Coordination Theory and How Can It Help Design Cooperative Work Systems?, ACM Conf. on Computer-supported Cooperative Work, New York, USA, pp. 357–370, (1990).
29. J. Rotmans and D. Loorbach, Complexity and Ttransition Management, J. Ind. Ecol., vol. 13, no. 2, pp. 184–196, (2009).
30. P. Cilliers, Complexity and Postmodernism: Understanding Complex Systems. Routledge, (2002).
31. J. G. March and H. A. Simon, Organizations, Wiley, Oxford, (1958).
32. H. Mintzberg, Structure in Fives: Designing Effective Organizations, Prentice-Hall, USA, (1993).
33. H. S. Nwana, L. C. Lee, and N. R. Jennings, Coordination in Software Agent Systems, Br. Telecom Tech. J., vol. 14, no. 4, pp. 79–88, (1996).
34. A. Bosman, Werkverdeling en Organiseren, 1st ed. Groningen, The Netherlands: Universiteitsdrukkerij, (1995).
35. W. J. Orlikowski and J. J. Baroudi, Studying Information Technology in Organizations: Research Approaches and Assumptions, Inf. Syst. Res., vol. 2, no. 1, pp. 1–28, (1991).
36. P. M. Herder, I. Bouwmans, G. P. Dijkema, and R. M. Stikkelman, Designing Infrastructures Using a Complex Systems Perspective, J. Des. Res., vol. 7, no. 1, pp. 17–34, (2008).