Selection of the Elements for a Continuously Operating Reference Station (CORS) Ecosystem Conceptual Model

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Keywords: Continuously Operating Reference System (CORS), Spatial Data Infrastructure (SDI), Ecosystem, Model

SUMMARY

A Continuously Operating Reference Station (CORS) allows for very accurate positioning in real time required for many applications including precise farming, emergency response, and disaster management. Since the first CORS initiatives were launched in the 1990s, a sustainable CORS business model has been subject to continuous discussion, and this is still a concern for CORS network implementation in the ongoing GNSS positioning development. Choices in policies determining the access and use of the CORS data are essential in this discussion. This paper presents the first stage of the "Access and CORS ecosystem" research which should guide CORS decision makers in their choice for sustainable access policy. In addition to the CORS network itself, the technical infrastructure, also the environment in which the CORS network operates is important for its performance. Therefore, the first step is the construction of a CORS ecosystem conceptual model. In this preliminary modelling stage, we assessed whether the concept of a Spatial Data Infrastructure (SDI) framework could be adopted to explain and understand the CORS ecosystem. Six primary elements are introduced to the context of CORS including data, human, policy, institutional framework, funding, technology and other infrastructures and standards. The findings imply that the concept of SDI can be applied to understand the CORS ecosystem. Further model development and validation are the next steps. Then the research will transform the conceptual model into a Decision Support System for CORS network implementation with a focus on sustainable access policy.

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1. INTRODUCTION

CORS Networks are essential infrastructures to support spatially related activities nowadays. As part of the geodetic purpose in origin, CORS sites have a fundamental role in establishing and giving access to the National Spatial Reference System (NSRS) which is a foundation for standardization of spatial data production [1]. It is projected that more areas of spatial activities will be relying on CORS Networks [2]. Even there exist the new correction services for GNSS positioning, but CORS network is still a foundation [3]. The main issue is about how such observation data from CORS should be utilized.

Many countries have implemented CORS networks, and a number of countries are going to implement CORS networks as national infrastructure. The success of CORS implementation is not only when the CORS networks are established, but it is also about their maintenance and utilization. The more CORS is accessed, the more it is utilized [4]. In addition to the CORS network itself, the technical infrastructure, also the environment in which the CORS network operates is important for its performance. The CORS network and its environment are mutually depending on each other. Together, the technical infrastructure of the CORS network and its environment can be considered an ecosystem, the CORS ecosystem.

To assess the performance of the CORS networks, a full understanding of the CORS network and its interaction with its environment is necessary. This may be captured in a conceptual model of CORS networks. Since CORS can be considered as the foundation of the geodetic infrastructure [4-6], it may benefit from the body of knowledge available from a closely related spatial data infrastructure: the concept of Spatial Data Infrastructure (SDI).

This paper, as part of the research "Access and CORS ecosystem", presents the element selected for the formulation of a CORS ecosystem conceptually. Considerations, opinions, theses and data from academia and industries are modulated with the concept of Spatial Data Infrastructure (SDI) resulting in potential elements of the CORS ecosystem conceptual model as the progress in the current research stage.

The paper is structured in six sections. The concept of CORS ecosystem is introduced in section 2. The applicability of the concept of SDI to CORS ecosystem is elaborated on in section 3. The modulation of the two concepts is shown in section 4. Section 5 discusses the outcomes as well as a conclusion and further research in section 6.

2. CORS ECOSYSTEM

Physically, a CORS Network refers to ground stations that function in continuously observing GNSS signals. The observation data is the primary product, which will be further processed as correction data for GNSS positioning. A CORS network includes four components: observation station, data transmission, central facility and data distribution [7]. These components have been implemented in different contexts. Scholars have paid attention to many essential aspects

of CORS implementation such as the managerial and organisational aspect [4, 8-10], the standard of CORS [11-14], utilisation of CORS [15-19], and the CORS business model [20-23]. Collectively, the works imply three critical stages of CORS implementation: 1) establishment, 2) maintenance, and 3) utilisation.

The establishment includes the physical installation of CORS, identifying the CORS purpose and stakeholders, and decisions about the spatial distribution of CORS [10, 12, 14, 19]. Moreover, the establishment is also about how to densify the CORS networks further to serve the demands as well as how to unify the existing different CORS networks. In particular, in a large area project, different providers and diverse purposes of CORS may occur. As to maximise the benefits of the CORS networks, it may require unification and densification of different CORS networks for area coverage and service availability [24].

The maintenance of CORS networks relates to activities to maintain hardware, software, equipment, station, building and vicinity of CORS networks. The process requires a site visit, software update, data quality control [1]. The maintenance is crucial for sustaining CORS networks after the establishment. It is also inherent with a considerable cost. The maintenance of CORS networks can be on a routine basis similar to other kinds of infrastructure, but it also can be in unexpected circumstance case by case. The maintenance of CORS has to be addressed by a long-term project plan [10, 19]. The funding should be assured.

The utilisation of CORS networks is the primary goal of CORS implementation. CORS utilisation itself can be defined as the effective use of CORS data. Basically, data is the primary product of CORS networks. From a data perspective, the CORS data product is similar to any other kind of data which can be used, reused and reproduced. Thus, the utilisation of CORS data can be expanded beyond its initiative, i.e. the data from CORS Networks for the geodetic purpose should be used for other activities such as cadastral and farming. Many factors influence CORS utilisation such as stakeholders, other infrastructures, and geography [5, 25, 26]. But one crucial consideration is that the utilisation of CORS is determined by the extent to which the CORS network can be accessed.

A term to explain a CORS network implementation and surround interactions is an ecosystem. Ecosystem or ecological system is well known from the biological sciences. It has been widely applied in many other fields. The word described the natural environment or organisation of animals, plants and organisms in an area. The elements in an ecosystem will not only co-exist, but also influence each other. They are also affected by a variety of external forces such as climate changes and natural disasters. The interactions between internal elements and environment cause the flow and cycle in the system [27, 28].

CORS networks, surrounding components and their relations can be precepted as a combination of livings in a system which is similar to an ecosystem. Thus, the concept of an ecosystem could be applied to CORS. In this paper, we define the CORS ecosystem as “the elements, their relations and the external influences to CORS networks and CORS data chain to be established, maintained and utilised”. There are two main parts of the CORS ecosystem: 1) the CORS Network and CORS Data Chain and 2) its surrounding environment.

3. SDI FRAMEWORK FOR THE CORS ECOSYSTEM

CORS networks are implemented in the CORS ecosystem. Scholars proposed models and concepts relating to CORS implementation. Those works elaborate elements and factors surrounding CORS network implementation from diverse aspects, i.e. managerial, economic, organisational, governing [8, 29]. In order to conceptualise a CORS ecosystem for the primary research, this paper, based on such considerations of the previous works, seeks the applicability of SDI as a framework for a CORS ecosystem conceptual model.

3.1 SDI applicability for a CORS ecosystem conceptual model

Historically SDI and CORS are initiated as infrastructures in the spatial data domain. They both share similar functions about spatial data. According to Strange [30], CORS initiatives were to be reference frameworks for spatial data interoperability in the 90s. Meanwhile, Onsrud and Pinto [31] explained that in the 1990s in the US, the evolution in spatial data had spread into many activities; different spatial datasets produced from different sources. The interoperability of spatial data was raised and later developed into the concept of SDI as the infrastructure, or essential physical and organizational structures needed to facilitate the availability of spatial data in such a way that the need of the agencies, organization, citizens, commerce and society are met [32-35]. The integral part of modern SDI is a robust geodetic infrastructure (CORS) that serves as the backbone of the entire system [36].

The interconnection between CORS and SDI can also be seen from a data and functional perspective. Since CORS data consists of position data and the main characteristic of spatial data is position inherence[37]. Thus CORS data can be considered spatial data. CORS data can be legitimately considered as spatial data [38]. The added value of CORS data or correction data is used to support the collection, production and utilisation of other spatial datasets. CORS networks also function as a modern geodetic reference framework [24] which underlies all kind of spatial data products. Based on this data and functional perspective, CORS data is part of and is underlying SDI.

In addition, the properties of both concepts are similarly exemplified by the hierarchical characteristics; CORS has several hierarchal layers varying from three to five tiers. Rizos [24] proposed a hierarchy of CORS in three tiers; local, national and global. The concept was also adapted by McElroy [14] into five tiers by adding local CORS Network installed between 4-7 years of operation in Tier 4 and the ad-hoc CORS in Tier 5. Also, the concept of SDI includes different hierarchical and interdepending levels (from a single organisation to local, national and global) Rajabifard and Williamson [33].

The SDI framework has been applied to some spatial data related fields which are closely related to positioning infrastructure such as the indoor location-based service which SDI components can be compared with the implementation of location-based service data [39]. Another application is the concept of Planetary Spatial Data Infrastructures (PSDIs) which is to support spatial data management, discovery, access, and utilization of foundational planetary data products: 1) geodetic control, 2) topography and 3) rigorously photogrammetrically controlled and orthorectified images [35, 40].

3.2 Selecting a framework of SDI for CORS ecosystem

The central concept of SDI is about facilitating the condition for spatial data to be best utilised. Such a concept has been developed and implemented in different contexts. The initial concept of SDI included five primary components (see Figure 1 left side): 'policy, access network, technical standards, people (including partnerships), and data', and these are grouped into two themes: human-data interaction (data and people), and the facilitating technologies (policy, access network, and standards) [33-35].

van Loenen [37] expands the pioneered SDI framework by including access network as part of technology, separating policies and institutional framework, and classifying financial resources as another critical element. In brief, his framework consists the data and the six elements elaborated as 1) Data: the datasets and data framework, 2) Human Resources: the natural elements in different sectors that require, build, use as well as enforce for the existence of spatial data, 3) Policies: a plan or course of action to achieve the goal of spatial data, 4) Institutional Framework: the responsibility arrangement of different players in the process of spatial data, 5) Technology: the scientific method, instrument, data and material directly and indirectly used to enable the spatial data chain, 6) Standards: the common requirements which allow the flow of spatial data between the processes and organisations and 7) Financial Resources: the interconnected resources to drive all elements of SDI (see Figure 1 right side).

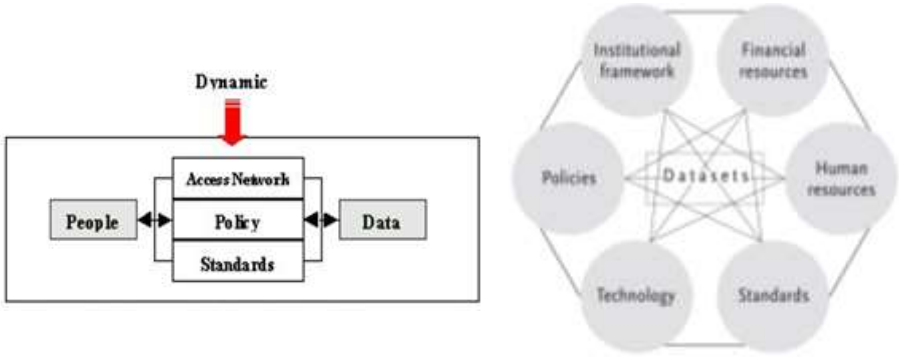

Figure 1: The fundamental concept of SDI by Rajabifard and Williamson [33], left and Components of SDI based on van Loenen [37]

The framework of Van Loenen also considers the relations between the elements since the interactions between them affect the flow of data. For example, institutions, policies, and financial resources decide who collects and gathers what information and who may use it. Sometimes they even require specific technology for the collection. Further, policies may decide on the quality of the information, e.g., require adherence to predefined standards. The quality of information collection relies on qualified people and the quality of the used technology [37]. The characteristics of this framework provide the applicability to CORS ecosystem conceptualisation.

4. CORS ECOSYSTEM CONCEPTUAL MODEL

Adopting the SDI framework to the CORS ecosystem, this paper considers the interconnection, the similarities and the differences between the two infrastructures. Some adaptations are applied as discussed in section **Fejl! Henvisningskilde ikke fundet.**.

4.1 CORS Network and CORS Data Chain

The central part of a CORS ecosystem is the CORS Networks and the CORS data chain. CORS networks include many stations. CORS data chain is part of GNSS positioning data chain which begins from GNSS signals and ends at positions on earth. In terms of CORS, the outcome from CORS networks is the data that might include but not limit to positions, time and satellites' conditions [26, 41]. The data from each CORS is both directly sent to utilise by users and sent to further computation and later distributed to users [42]. Different GNSS positioning techniques may affect difference CORS data chains, but the primary data stages are (1) GNSS signals, (2) Observation Data and (3) Correction Data (see Figure 2).

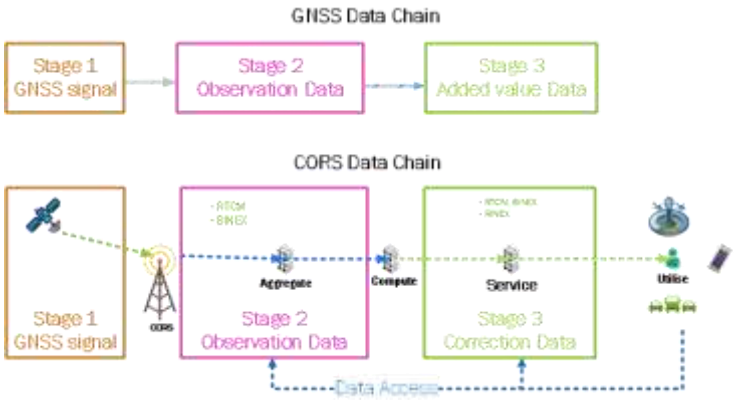

Figure 2: CORS Data Chain

From a data perspective, the CORS data chain is the flow and transformation of data in a CORS ecosystem.The data in such data chain can be considered as a spatial data value-adding process in which new value is added to the original input step-by-step along the chain. The first data stage is the GNSS signals. The signals are observed and collected at each CORS (station) as observation data (CORS data stage 2). The observation data can be further processed into correction data (CORS data stage 3), or it can be directly used by users. Data in CORS data chain is as the framework dataset when the data is used as part of the standard coordinate system. On the other hand, it can be used as a dataset for further positioning by users (after-the-fact position) [7].

4.2 Human element

The human element refers to actors whose actions contribute to the CORS ecosystem. The human can be considered in two aspects 1) The actors and their actions in the CORS ecosystem and 2) the actor capital.

Actors are the stakeholders who affect or are affected by the actions, objectives and policies in the CORS ecosystem. The stakeholders in the CORS ecosystem are considered as part of GNSS stakeholders who are in public and private sectors. Their actions relate to CORS network implementation. The actions may not directly affect the data characteristics, but they may influence other elements that affect the flow of the data such as the establish CORS network, utilise CORS data, regulate the implementation, add value to the data. Such actions may rely on their interest and affiliations. Categorised by the actions, the actors are described as users, providers or operators and regulators. The providers can be separated into data collectors, aggregators and distributors. Moreover, a stakeholder might appear in more than one categories.

Actor capital is about knowledge, culture, demands, capabilities of people in implementing CORS network in a CORS ecosystem. Giving a example of providers, they are not needed just to operate and maintain CORS networks, but also to process the collected data and analyze the obtained results for various applications and interests [16], Hence relations between CORS network operators, data custodians, researchers, developers, data providers and data users are essential. In practice, stakeholder networking is also critical for CORS site operation; particularly those sites remote from network control facilities [29].

4.3 Policies and Institutional Framework

Even though the data flow along the chain by the technology and other physical components in the CORS ecosystem, the objectives of the flow are designed by the contributions of the stakeholders in the CORS ecosystem. Such collective contributions are seen in policies and institutional framework which may refer to the driving forces, mechanisms, instruments, and arrangements to achieve the goal(s) of CORS implementation. These factors are formulated at the beginning of CORS network implementation such as responsibility, leadership, the condition to ensure interoperability of CORS data and service, and the availability of funding. However, the policy and institutional framework can be changed according to the change in the ecosystem as well.

The policy and institutional Framework in the CORS ecosystem also relate to vision, access policy and business model of CORS implementation [2, 43], legal perspective of CORS data [16] and licensing agreement for the right on CORS data [10]. Vision and law are the beginning point in directing the use of data as can be seen in many cases. The national space policy relating to GNSS is also a vital policy affecting CORS implementation [10].

In terms of the investment, policy and organisational arrangements are guidances for CORS network providers in both the public and private sector for investment strategy. Without the policy and arrangements, uncoordinated and independent CORS providers can lead to duplication and poor distribution of the CORS network [10]. Moreover, the policy is also about the adequate resources to CORS projects under the purposes and the needs of their end users. In such manner, CORS business model has become an issue in policy and institutional framework since the early time (the 90s) of CORS implementation [30, 44] until the today it is still a concern for CORS system development [9, 45, 46].

4.4 Technology and Relevant Infrastructures

Technology and related infrastructures in the CORS ecosystem which provide conditions for CORS implementation and the observation, processing and distribution of data. The technology relates to all data stages such as signal encoding, data processing, signal jamming-spoofing prevention. The activities between each data stage require communication and power supply. The infrastructures supporting CORS have to be 24/7 available.

In terms of communication infrastructure, technology is underlying the flow of data in the CORS data chain. The network connectivity between CORS and central processing systems facilitate the CORS network to aggregate, compute and distribute correction data [29]. the communication such as virtual private network (VPN) tunnels also allows direct and secure access to support monitoring and solving the problem at CORS [13]. This requires internet service which is based on communication infrastructure. Thus thorough feasibility of communication coverage should be part of the ecosystem where CORS is implemented [23].

Power infrastructure is vital as part of CORS and as part of CORS ecosystem. Basically, the power supply is a condition to establish CORS networks [1, 44, 47, 48]. The providers have to assure that there is power for the equipment in CORS. However, in some areas that have no power infrastructure, the alternative power source such as solar energy panels might be an option. Moreover, the Uninterruptible Power Supply (UPS) unit is also a requirement for each CORS site[13].

4.5 Standards

The standards in the CORS ecosystem may be classified as Data standard and Station (site) standard. Such standards also support cooperatives between actors from different organisations. It boosts the human productivities [17].

In the CORS data chain, in each data stage, the data may be in different formats. However, as interoperability is vital for CORS implementation, the data have to be interoperable. The standard formats have been used, and the development of data format standard is going on in particular when multi GNSS data is an opportunity for improving positioning service [46]. For example, the well known standard formats for real-time correction data broadcasting are RTCM by Radio Technical Commission for Maritime Services and NMEA by National Marine Electronics Association. For the data archive, the RINEX or Receiver Independent Exchange Format format is widely adopted.

Meanwhile, the station standards describe maximum uncertainty and stability requirements for the tiers in which CORS is placed [11]. The site standards are in the form of guideline for CORS site. In smaller units of CORS site, the equipment installed is under International Organization for Standardization (ISO) in particular ISO17123-8 which concerns GNSS field measurement system.

Such standards are defined by GNSS public and private organisations in global, local and national levels such as the International GNSS Service (IGS) of International Association of Geodesy (IAG), University NAVSTAR Consortium (UNAVCO) as well as some GNSS manufactures. Some organisations beyond GNSS also play a role in defining the standard in CORS data chain, for instance, the GNSS signals are under International Telecommunication Union (ITU) radio regulation on the global scale. There are also national, and organisation standards are existing in many countries. It could be remarked that the standards are aligned with the global standard by IGS.

4.6 Financial Resources

Availability of funding is critical for all elements of the CORS ecosystem. Basically, the cost of establishment is from the providers. The budget constraints affect data characteristics and standards. It can also limit the technology applied in the. In turn, the benefits of CORS Networks are numerous, and cost savings are essential drivers [49]. As a consequence, the financial aspect of CORS should be considered based on the cost and benefit.

In particular, CORS implementations is about the budget feeding the CORS ecosystem. In this matter, the Institutional Arrangements determine funding sources and data policy in each CORS ecosystem. Even though the key to a profitable CORS is to generate the corrections, which also plays a role in the development of a profitable product [50], the actors, such as providers in public and private sectors, may have different perspectives on the benefit of providing.

Provider in the public sector may consider CORS networks as infrastructure to support all kind of users for better positioning similar to the classic way of financing classical geodetic networks; at a minimum cost [22]. In contrast, private providers may see implementing CORS networks as a business service at market prices. For both public and private sectors, there also exist other data business models such as subsidies form through equipment purchasing with free data use [22]. However, the service cost is not the most crucial factor of some users, but the service assurance might be more prioritised [51]. Such models might be applicable to the CORS network implementation. It is remarkable that funding is vital for all elements in the CORS ecosystem. The models for financing are based on each context.

4.7 Relations Between Elements of a CORS Ecosystem

The elements are not existing alone. There also the relations between elements. Considering that a CORS network produces data flown in the CORS data chain, this activity is the main activity and product in a CORS ecosystem. But the activity is driven by other elements which exist and interact with each other in order to support the main activity. Basically, each element affects and is affected by all other elements direct and indirect ways as described in Table 1.

5. DISCUSSION

The formulation of potential CORS ecosystem elements based on the SDI framework is elaborated. In the process of element exploration and selection, the mutual and different aspects between CORS and SDI are found. CORS Networks, on the one hand, are physical infrastructures supporting spatial data activities. On the other hand, CORS data product is spatial data itself. Thus CORS networks, from a functional perspective, can be considered as an integral supporting part of SDI implementation. Meanwhile, CORS networks from the data perspective can be the datasets in SDI. Moreover, the element selection is the first stage for modelling the CORS ecosystem, so the element formulation should provide the simplicity for the further modelling step. Taken these considerations with the adoption of SDI framework to CORS ecosystem, there are some adaptations applied.

The first adaptation is due to the fact that the difference. The central part of SDI is defined as the data element which includes spatial datasets and spatial data framework. Whereas in a CORS ecosystem, the central element is CORS networks as a combination of stations and the CORS data chain.

The second adaptation is the integration of policy and institutional framework as one element. Since both aspects are interconnected when considering in the context of the CORS network. Policy can determine the arrangement of the organisation. In turn, the organisations in different levels and with different responsibilities can also design their own policies based on the higher policy and the arrangement they are assigned. It is too complicated to classify the two elements. Thus, the spectrums of the two elements of SDI are merged in applying to CORS ecosystem.

The third adaptation is to expand the technology element to cover other infrastructures. Since CORS networks are more physical infrastructure, even though the service they provide is non-physical but it relies on other physical infrastructures; such infrastructures as part of the CORS ecosystem. Besides, the infrastructures for CORS ecosystem are connected to technology, i.e. 5G communication, alternative power supply, data centre etc. These two elements affect another element similar. For example, 5G is telecommunication technology affecting the data

flow, but the technology itself (5G) requires infrastructure. Based on such arguments, the technology and infrastructure are combined together.

Table 1: The relations between elements in a CORS Ecosystem

CORS Data	Financial Resources	Policy & Institutional Framework	Human Resources	Technology& Relevant Infrastructures	Standards
Financial Resources	Availability of funding is critical for all elements of the CORS ecosystem. For CORS data chain, budget constraints influence data characteristics. [8, 43, 52]	Institutional Arrangements determine funding sources and data policy [6, 8, 22, 53]. The policy will guide the decision of public and private investment [10, 51]	Funding is based on human decision [8, 11]. It also affects human capital in CORS ecosystem.	Funding is essential for technological accessibility. Technology also boots the growth of funding[8, 53].	Funding concerns the standards of data, station (tier) and equipment [11].
Policy & Institutional Framework	Policy and Institutional Framework concerns the means by which the goals will be achieved. It enforces the collaboration between organisations [10, 11, 13, 25], determines the data characteristics; purpose, quality [37, 54, 55] and action arrangement; custodianship, ownership, regulator etc.		Who (actor) in which organization(s) will act what? [37, 56]. It can be feedback sources for policy development [57]	Technology is a consideration for policy design such as the data access arrangement[10].	Standard support interoperability between organizations [1, 11] Policy endorses data and service standard [10, 25].
Human Resources	Stakeholders who take actions in all stage of implementation and relate to every element in the CORS ecosystem. With their interest and affiliation, the stakeholders which can be categorized based on their Action Aspects; providers and users[57] and Actor Capital ; knowledge, culture[16],			Technology supports actions in the ecosystem[53]. Human capital relates to technology utilization.	Standards support cooperatives between actors. It boots the human productivities [17].
Technology & Relevant Infrastructures	Science, instrument and methods used to achieve CORS implementation goal(s) which may include CORS data chain; data standard, data process (collecting, storing, monitoring, and distributing)[8, 53] or CORS (station); hardware, software[53]. The Relevant infrastructures may include a power supply, communication and road or other means of site access.				The technology relates to the standards of data, hardware and software[37]. Standards also define the technological requirement.
Standards	CORS (site) standards and CORS data Standards are issued by many organizations from global to national level. Standards can be seen from CORS hierarchy which classifies CORS in different tiers [17] which determines the specification of the site, equipment, Antenna, Monument, Coordinate derivation, Power, Communications, Data Formats, Reliability of service, Stability, Additional Site Sensors, Data Access [11]. CORS Data standard: data both real-time and archive in each stage can be in different standards (open standards and manufactory standards). By influencing the primary element, standards also influence other elements in CORS ecosystem.				

6. CONCLUSION AND FURTHER RESEARCH

In order to construct a conceptual model of the CORS ecosystem to understand sustainable CORS implementation, this paper explores the application of the concept of SDI to the CORS ecosystem. The paper found interconnections and similarities of CORS and SDI in the goals and in the characteristic of supporting spatial data collection, provision and utilisation.

Although CORS and SDI overlap in terms of the goals and functions, some adaptations are required to fit the SDI conceptual model to CORS. In this preliminary stage of the research, the SDI framework is applicable to represent the conceptual model of the CORS ecosystem.

For further research, the elements and their relations in the CORS ecosystem will be inputs to construct a simulation model by System Dynamics methodology. The model will be further developed and validated by experts and stakeholders in an iterative process. The final model will be transformed into a Decision Support System for CORS network implementation. The DSS will be applied to determine a most appropriate access policy for CORS implementation as the primary goal of the PhD research presented in this paper.

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