Investigating an Agent Based Modelling approach for SDI planning: A case study of Tanzania NSDI development

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Abstract

Spatial Data Infrastructure (SDI) provides a platform for spatial data sharing and is a key for sustainable development. Developing countries, including Tanzania, are at different stages of implementing SDIs. The importance and advantage of implementation lie in the fact that considerable funds can be saved by avoiding duplication of data, and improving quality of decisions making as well as public services. However, SDI is very complex in nature, including many influencing factors and different stakeholders. This paper investigates the possibilities of using Agent-Based Modelling (ABM) for simulating an SDI development process in Tanzania, for better understanding and making better planning. The roles and actions of organizations were identified through interviews, and the results were analysed. The behaviour of individual organizations (stakeholders) while interacting with the system were observed and analysed. The growth results in terms of data availability, standards, and data sharing for each organization were plotted and priority tables were generated. The model was evaluated for consistency and the results were judged to be within a reasonable range. The ABM simulation depicted the main attributes of agents, their roles and their interactions while pursuing SDI development in Tanzania. The results will help SDI planners and stakeholders to understand the roles of partners and prioritize activities and actions for successful SDI implementation.

Keywords: *Spatial Data Infrastructure, Agent-based Modelling, simulation, SDI planning, Tanzania*

1. Introduction

Spatial Data Infrastructure (SDI) is the main framework for access to distributed geospatial data (Budhathoki and Nedovic-Budic, 2007). Spatial data, or geospatial data, or geographic information, are the data and/or information that identify the geographic location of features and boundaries on Earth, such as natural or constructed features. Spatial data availability and accessibility provide efficient services to citizens in domains of e.g. emergency services, public utilities, environment, land use, transport, and agriculture (Janssen et al., 2011, Wray and Cheruiyot, 2015, Käyhkö et al., 2018). SDI is an evolving concept including interactions between various components that are dynamic in nature (Rajabifard et al., 2003). It is complex (Grus et al., 2010, Mansourian and Abdolmajidi, 2011, Hendriks et al., 2012, Mansourian et al., 2015, Maphale and Moreri, 2018), its implementation is quite challenging in most national contexts, and local stakeholder's participation is often problematic. For instance, the development of a National Spatial Data Infrastructure for Tanzania (TNSDI) is highly prioritized by the Survey and Mapping Division, Ministry of Lands and Human Settlements Development (MLHHSD), Disaster Management Department at the Prime Minister's Office of Tanzania (Becker, 2011, URT-PM, 2011) and the National Bureau of Statistics (URT, 2010a). However, generally in Tanzania and other developing countries, the progress for launching a National SDI has been very slow (Makanga and Smit, 2008, De Vries and Lance, 2011, Hagai, 2017, Ngereja et al., 2018, Lubida, 2019).

Implementation of SDI requires efficient coordination among stakeholders, as well as standards to govern data transactions. Many governments thus are building SDI for their nations or regions. Likewise, African countries are at different stages for building SDIs (Lance, 2003, Makanga and Smit, 2008, Gelagay, 2017, Ingwe, 2017). In Tanzania the NSDI policy proposal is in place since 2007 (Lugoe and Yanda, 2007), pending government authorisation. The delay in approving the proposal is partly due to various challenges such as lack of awareness, lack of proper coordinating body, limited funds and lack of political commitment (Lubida et al., 2015, Hagai, 2017, Agbaje and John, 2018, Ngereja et al., 2018). The policy proposal is a result of workshops, seminars, and conferences held in order to create awareness and sensitization campaigns. For instance a workshop on open-source geospatial solutions in land and forest mapping (Malaki, 2015), a workshop on environmental data management in Tanzania (Larsen, 2014) and the Tanzanian NSDI stakeholders workshop organized by Regional Centre for Mapping of Resources for Development (RCMRD) in 2016, which brought together high-level officials from various governmental and non-governmental institutions in Tanzania. The workshop aimed at enhancing awareness on the importance of having an operational geospatial data infrastructure in Tanzania (RCMRD, 2016).

The success in SDI development is directly associated with policy making and effective planning. Several authors have addressed different methods for SDI planning and modelling, including coproduction (Albrechts, 2013), Ecosystem Approach (EA) (Alexander et al., 2012), Actor Network Theory (ANT) (Budhathoki and Nedovic-Budic, 2007, Vandenbroucke et al., 2009), the System Dynamics model (Mansourian and Abdolmajidi, 2011) and Agent-based Modelling (ABM) (Scholl, 2001)

Albrechts (2013) used coproduction to reframe strategic planning. Coproduction focuses on ensuring the need for citizens are met by combining the provision of public services needed with the building of a strong, resilient, and mutually supportive community. Alexander et al. (2012) used EA for management of Marine Spatial Planning. EA is a Spatial Decision Support System (SDSS) approach that combines GIS, spatial Multi Criteria Analysis (MCA), touch table, and stakeholders' workshops. The method identifies important gaps in existing spatial data and helps to fill these through interactive user inputs. ANT is used instead of conventional social theory to examine and explain the interaction between information technology and society. Budhathoki and Nedovic-Budic (2007) studied ANT and observed that it grows through the process of translation, and thus can be used to study SDI. The reason is that SDI involves networks and internet-based access points acquiring data and services, and the translation process is one way of understanding and cultivating SDI. Also Vandenbroucke et al. (2009) proposed an extension that leads to a network perspective on SDI. Its capability to assess the SDI was tested using a social network analysis focusing on the network structure parameters density, distance, and centrality.

The System Dynamics technique (SD) has been used to study SDI, its affecting factors, and their interactions. In addressing the complexity of SDI, using modelling systems, Mansourian and Abdolmajidi (2011) studied the applicability of the system dynamics technique for modelling and simulating the development process of SDI. Results showed that the technique is capable of modelling the interactions among the factors affecting SDI and the associated feedback loops and delays. In another study, Mansourian et al. (2015) developed a methodology based on system dynamics and the community of practice concept for SDI planning in Tanzania. The results showed future effects of today's plans and helped groups involved to understand more about the SDI components.

An Agent-Based Model (ABM) is a computational model simulating actions and interactions of autonomous agents which are either individual or collective entities, such as organizations or groups for the purpose of assessing their effects on the system as a whole (Grimm and Railsback, 2005). It can provide a more realistic view when dealing with a decentralized and complex system that consists of many interdependencies. For instance, Berglund (2015) used ABM for water resources planning and management where ABM created new insights for water systems as dynamic systems to explore complex behaviour as it changes over time. Zellner (2008) examined the potential and limitation of agent-based models in understanding complex systems where the environmental planning agenda was described using ABM within a participatory institutional context. Zellner et al. (2012) used ABM for environmental planning where the ABM was found to be effective for the use in a collaborative planning exercise. (Rajabi et al., 2016) and (Rajabi et al., 2018) used ABM in spatial epidemiology in order to study Leishmaniosis.

In most countries, governmental policies have created new stakeholder groups making demands upon SDIs. Different stakeholders gain interest in, and focus on, geospatial data and with the advancement of open source initiatives a bottom-up approach of SDI is emerging (Lance, 2003, TZGISUG, 2013, Käyhkö et al., 2018). For example, non-profit agencies and non-governmental organizations are increasingly involved in planning, service providing, and administrative processes. A growing number of these groups are beginning to use geospatial data and technologies in the day-to-day activities. The interactions between these organizations and governments and SDI have not been recognized by researchers or policy makers as part of data sharing and data availability efforts, so little is known about their role when planning a strategy for SDI development. Moreover, the feasibility and implications of possible strategies regarding these stakeholders cannot be explored using conventional methods, since they only explore macro level SDI investigations. Other existing planning methods have weaknesses such as limitations in explaining efficiently the interactions among the objects, because they model the SDI at a macro (top) level without modelling interaction between individual objects. For example, “stakeholders” are considered as an element, and interactions between stakeholders, or how each stakeholder implements standards and policies, are not modelled. The ABM concept is a bottom-up approach that explores the influence of interactions at micro level (Bonabeau, 2002) on the ability of the entire system. Emergent phenomena are results of interactions between individual entities. This far no research using ABM for a detailed study and simulation of the SDI development process has been reported.

This study addresses this missing link, by applying Multi Agent Simulation (MAS). The approach is done through the investigation of the possibilities, strengths, and weaknesses of Agent-based Modelling (ABM) for SDI simulation and planning, with Tanzania as a case study. Through this study, the knowledge of interaction among the organizations participating in building SDI will help stakeholders to better understand and make better decision. This is of high importance for proper planning and implementation of a successful SDI in Tanzania.

This paper is organized into four sections; section one presents the introduction and a background of the subject area. Section two describes the methodology where ABM is presented based on a standard protocol, consisting of Overview, Design concepts and Details (ODD). Results and discussions are presented in section three and finally the conclusion of the study is given.

2. Methodology

2.1. Case Study

The United Republic of Tanzania is situated in East Africa, with a total area of about 947,300sq. km. It is located on the East Coast between latitudes 1° and 12° S and longitudes 29°-41° E (refer Fig. 1). The country is surrounded by eight countries which are; Uganda and Kenya to the North, Indian Ocean to the East, Mozambique and Malawi to the South, Zambia to the South West, and Democratic Republic of Congo, Burundi and Rwanda to the West. According to a 2019 census projections, Tanzania had a population of 55.89m (URT, 2018a). Several stakeholders potentially linked to an NSDI have been identified in Tanzania (Mtalo, 2007, Larsen, 2014). Main organizations for spatial data are the Surveys and Mapping Division (SMD), the National Bureau for Statistics (NBS), the National Environmental Councils (NEMC), and the Sustainable Management of Land and Environment in Zanzibar (SMOLE). SMD, under the Ministry of Lands Housing and Human Settlements Development (MLHHSD), has the main role to provide expertise and services in the provision of survey charts, plans, and maps. It has functions to conduct and oversee execution of topographic, geodetic, hydrographic, and cadastral surveys, to transform survey data into charts, plans and maps, to update charts, plans and maps, to survey and inspect national and international boundaries, and to develop capacity on hydrographic surveying and charting.

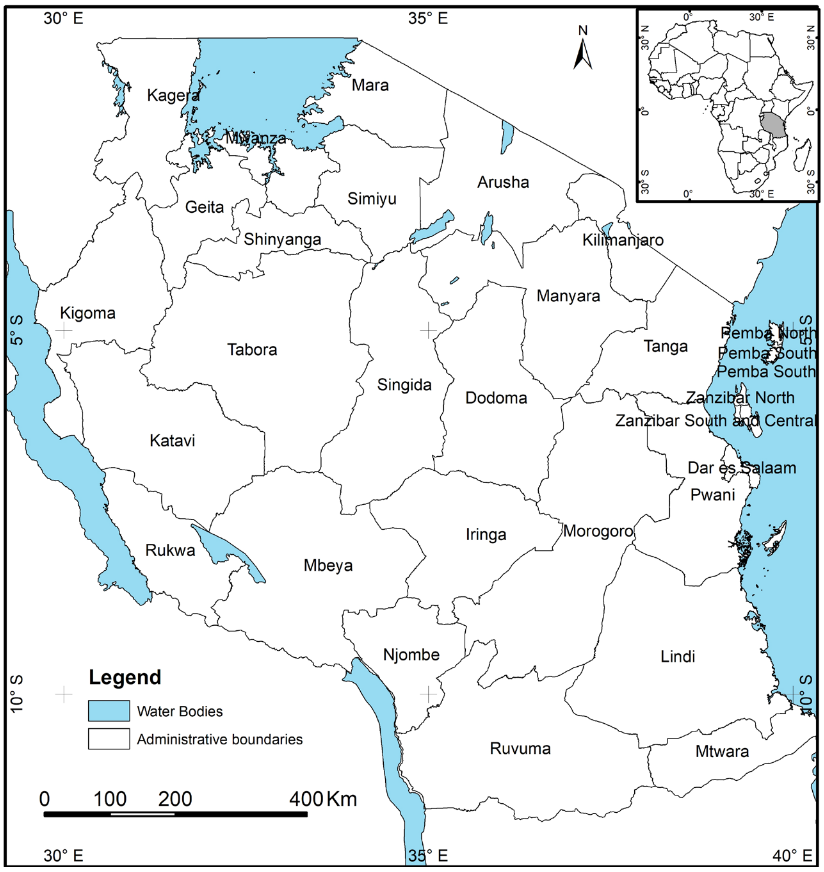

Figure 1: Map of Tanzania showing its location in Africa as well as the administrative boundaries inside Tanzania

As part of improving land delivery services, SMD has developed several application programs such as the Land Rent Management System (LRMS), the Surveys Registration System (SRS), the Management of Land Information System (MOLIS), and the Integrated Land Management Information System (ILMIS) (Katambi, 2009, Mwaikambo and Hagai, 2013, Laseko et al., 2018). Apart from these, the government implements a project on ICT technology where all regions and districts in Tanzania are linked with optic fibre cable in order to provide reliable and affordable internet to a wider area.

The NBS is an autonomous, public institution mandated to coordinate the production and dissemination of official statistics to the Government, business community and the public at large in Tanzania. It is the central depository for a wide range of economic, social and demographic statistics about the country. NEMC and SMOLE are mandated to undertake enforcement, compliance, review, and monitoring of environmental impact assessments, research, facilitate public participation in environmental decision-making, raise environmental awareness, and collect and disseminate environmental information. They use spatial data and GIS software in their day-to-day activities.

2.2. Field survey and data collection

A mixed method approach was adopted and used to capture useful information for the ABM. The data collection included questionnaires surveys, meetings with stakeholders, literature search and reviewing policies, as well as other documents essential for successful SDI implementation in Tanzania. The main data required for the ABM model are: (1) to identify the potential organizations for partnership in NSDI implementation, either as data producer or data user, (2) to identify roles of different organizations in implementing spatially related projects, (3) to identify activities done by the organizations related to SDI, such as spatial data collection, database and geoportal creation, and setting and using standards. (4) to identify actions by organization meant for successful implementation of spatial projects. The data collected were important for identifying and modelling interactions and priorities, observe the emerging behaviour, and helped to have an idea regarding future status of the SDI in the country.

Questionnaire surveys were used to obtain information from staff at various organizations working with SDI related activities. The questions were mainly related to knowledge about the SDI, awareness level, knowledge of standards, and technological level of organization. Other questions were related to the financial resources for hiring, training, improving technology and improving standards, and promoting SDI culture. At least three staff members at every organization were interviewed. Twenty four organizations from different parts of Tanzania were involved in this research. The targeted organizations were those that acquire, maintain, and/or use spatial data. The organizations were involved in sectors related to road construction and maintenance, water distribution, waste water management, electricity, telecommunications, postcodes, addresses, mapping, and land use/land cover data. Most of them had established local databases, while others used local servers, to manage spatial data.

The secondary data obtained include the National Environmental act, the National Information and Communication Technology Policy, the National Bureau of Statistics strategic planning, and the National Spatial Data Infrastructure policy proposal 2007. After data collection, all field data were analysed and used to identify the main actors, attributes, and estimates of minimum and maximum values for each attribute.

2.3. Agent-based Modelling for simulating SDI development

The research team developed the ABM based on the analysis of information obtained during field data collection. The Delphi approach (Fowles, 1978) was selected and used by the research team, in collaboration with stakeholders, in order to develop the model and update information necessary for running it. The ABM conceptual model is described in the section below using a standard protocol, consisting of Overview, Design concepts, and Details (ODD) (Grimm and Railsback, 2005, Grimm et al., 2006). According to the ODD model, the following subcategories are presented; purpose, state variables and scales, process overview and scheduling, initialization and sub-models.

2.3.1. Purpose

The purpose of the model is to better understand the interactions between main agents; organizations, projects, and actions in pursuing a number of objectives. Agents have roles to fulfil based on some set out rules. Organizations are the ones performing projects and actions related to SDI, represented by three main groups, namely Public Agencies, National Mapping Agencies (NMA) and Ministries. The Private Sector Companies (PSC) are in a subsidiary group since they are to be hired in order to satisfy the requirements for the main groups. Public Agencies in Tanzania are part of the government established by law for a particular purpose. They are departments, commissions, authorities or boards that operate with a partial degree of operational independence in exercising or implementing projects. National Mapping Agencies (NMA) in Tanzania represent a department within the Ministry with a lot of knowledgeable people, but lack a degree of operational independence. Ministries are government departments that focus on a common and wide goal that is not specific. In this case it is difficult for a ministry to focus on SDI unless culturing is done. Sub models for grouping organizations are described in Section 4.5 below. The *projects* are arranged into four categories:

- Project 1. Spatial data production; represents map production including capturing three dimensional positions, i.e. horizontal (x, y) and vertical (z), of features and representing them as layers in GIS. The capture process is done by ground surveying, photogrammetry, remote sensing and scanning, and/or digitizing maps in a GIS environment.
- Project 2. Spatial data sharing; refers to using geoportals as a gateway to find and access geospatial information and related services through the Internet. Geoportals are essential for Spatial Data Infrastructures (SDIs).
- Project 3. Using standards; Project 3 refers to developing data standards and procedures focusing on standards that facilitate the development, sharing, and use of geospatial data.
- Project 4. Creating and maintaining database; is concerned with establishing and maintenance of database for spatial data. This is important since all captured data will be stored and managed in the database.

Actions are the decisions taken by organizations to fulfil the requirements which hinder them from performing projects. The following actions were defined:

- Action 1: Training existing staff to gain required knowledge and skills (e.g. using GIS) to be able to fulfil spatial information related tasks in the organization.
- Action 2: Employing new skilled staff members who can take care of spatial information related tasks in the organization in order to carry out the projects.
- Action 3: Improving technological level of the organization by e.g. upgrading computer hardware, software, etc. needed for spatial data management and sharing.

- Action 4: Increasing awareness regarding importance and use of SDI, through e.g. holding workshops to gain the support of stakeholders for the successful development of SDI.
- Action 5: Financing the projects. This may be governmental budget given to the organization for the implementation of the projects or income of organization through e.g. selling services. We assume annual governmental budget in our modelling.
- Action 6: Updating spatial data. The databases have to be updated on at least monthly basis and the updated data has to be accessible through geoportals.

The model is built on the assumption that in order to attain the best level of SDI development, the organizations should work towards fulfilling the two objectives proposed in this study. The first objective is to increase spatial data availability, and the second one is to maximize spatial data sharing and the use of standards. Finally, the assessment is done on how the interactions are affecting the SDI development process in Tanzania.

The first objective is dependent on Projects 1 and 4 (spatial data production as well as creating and maintaining database). The reward is added for any completed project as illustrated by the following equation:

$$\text{Obj.1:=}\sum reward\ from\ p1(spatial\ data\ production)\ and\ p4(Geodatabase) \quad [1]$$

where p = project

For the second objective, focus is on increasing spatial data sharing and using standards for all spatially related activities. The reward is added to the organization for any completed project 2 and 3 as illustrated by the following equation:

$$\text{Obj.2:=}\sum reward\ from\ p2(spatial\ data\ sharing)\ and\ p3\ (standards\ ) \quad [2]$$

2.3.2. *State variables and scales*

In the ABM for SDI development, three main agents were represented, as mentioned above. These agents interact with each other according to the roles and set out rules. Figure 2 illustrates the relationships between the agents in the model using a UML class diagram.

Initially, the organizations randomly select objectives and then check if they are capable of fulfilling them. The checking involves nine attributes used to characterize the organizations (refer Table 1). Spatial knowledge index is a normalized average of knowledge relatives among the organizations. The attributes were selected based on SDIs most influencing factors (Rajabifard et al., 2003, Mansourian and Abdolmajidi, 2011, Mansourian et al., 2015). Data availability as an attribute refers to the amount of data that is owned by an organization and that can be shared.

The organizations with enough capacity were capable of carrying out the projects. In case the organization has insufficient capacity, an action is instead performed in order to satisfy the attributes. Sometimes an organization, which is lacking capacity for certain attributes, may need to hire Private Sector Companies (PSCs) to carry out projects. Checks are performed on budget, technological level, knowledge, and standards as basic requirements for an organization to hire PSCs. As illustrated in Figure 2, organization and PSCs are linked with class diagram hire_PSCs.

Completing projects and actions improves the attributes for the organizations. As Figure 2 shows, organization are linked by projects and actions using class diagram "perform_project" and "perform_action". Through this process, the project output is a reward, and includes increased reputation of an organization.

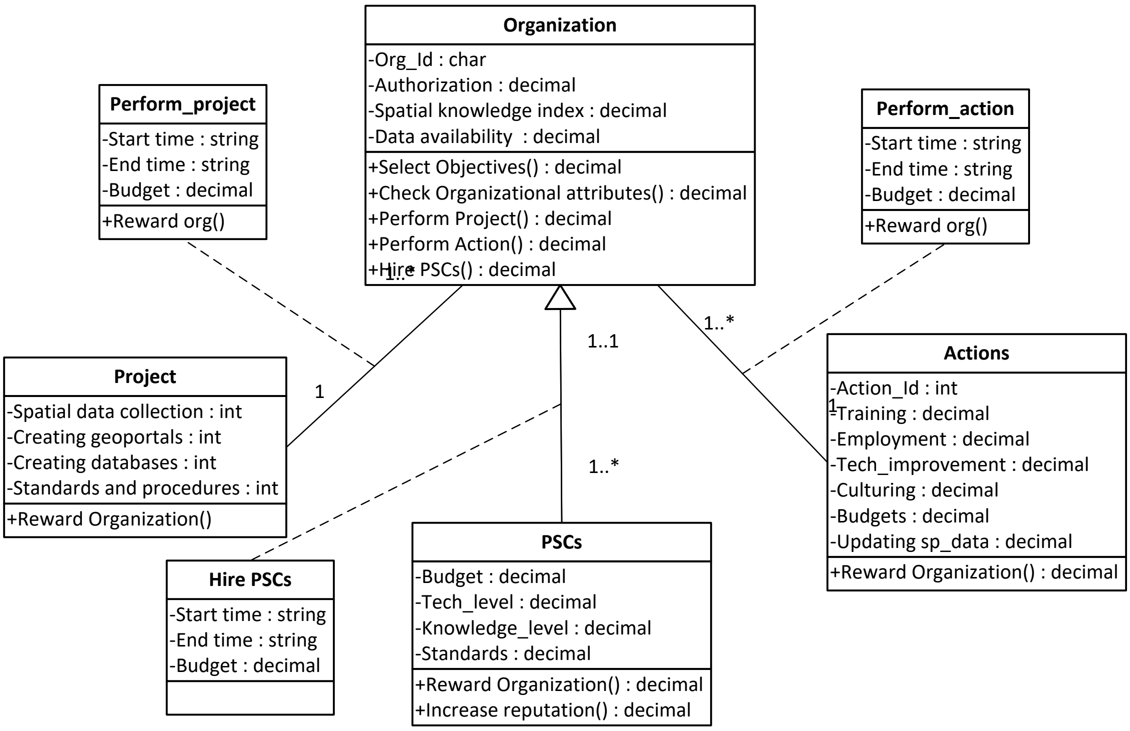

Figure 2: ABM for SDI development presented by a UML class diagram showing relationship among organizations, projects and actions.

2.3.3. Process overview and scheduling

The modelling process involves organizations, randomly selecting objectives. After this selection, the main attributes for the objective are prioritized and increased. The range of values is set, and for each simulation the value is selected randomly within the specified range. In order for the agents to adhere to their roles and follow rules set out, various checks are set in the modelling process. The first check is done to compare the organizational capacity to the requirements required to carry out the projects. If the organization has enough capacity, then the project is done. If not the organization has to perform actions to improve its capacity. A second check is done to see whether the organization needs to hire a private company or do the project by itself. A third check is done to evaluate if enough standards to carry out the project have been set. A fourth check is done to evaluate budget requirements.

In the simulation process, the length and timing in the model are different depending on the nature and the type of projects or actions selected. Production of spatial data is estimated to be finalized for the duration of five years, geoportal and data sharing is estimated for a duration of one year, creating a geodatabase lasts for five years, and developing data standards and procedures is estimated to be completed within one year. Regarding the actions, training is estimated to be done in 6 months, employment within two years, technology improvement within one year, culturing within one year, budget updated once per year, and updating spatial data on a monthly basis.

The modelling process is represented by a sequential diagram, as shown in Figure 3, that shows the interaction of agents and attributes and the order those interactions occur in the SDI development process. In Figure 3, instances are placed across the top of the diagram. The processes are represented vertically while interactions are shown as arrows. All instances are linked by arrows with messages indicating the type of interactions performed.

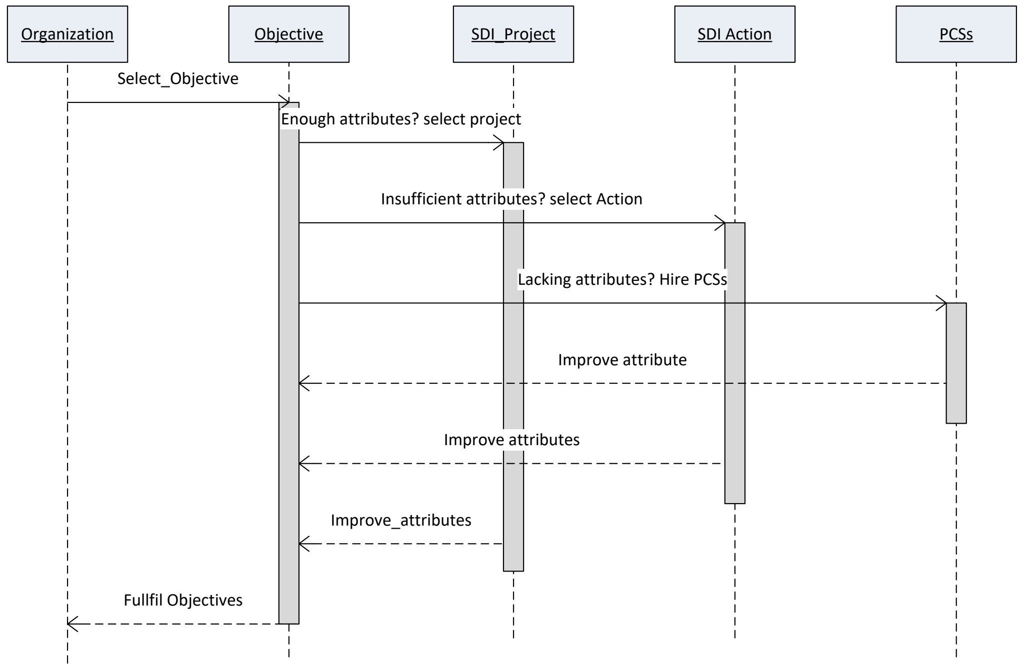

Figure 3: Sequential diagram showing the interactions among agents and attributes in the SDI development process.

2.3.4. *Initialization*

The agents and attributes were modelled in the ABM system using the Netlogo software, authored by Wilensky (1999) (Wilensky and Rand, 2015, Abar et al., 2017, Gunaratne and Garibay, 2018). The Netlogo environment consists of turtles and patches (refer Appendix I). Turtles, also called mobile agents, represent agents that moves from one point to another according to given instruction or criteria. Patches, ground over which turtles can move, are stationary agents that are represented by two dimension grid of 33 wide x 33 high square cells that are, 1089 in total (Wilensky, 1999). Organizations are represented by turtles while projects and actions are represented by patches. The connections between agents are established by links representing networks among turtles, and observers who control the model.

Initial variables for the model were based on previous work by (Mansourian et al., 2015), and estimation from field work data. Table 1 shows the different attributes with minimum and maximum variables for each organization. The variables represent the level of the current status of organization, as well as the maximum status that can be reached after performing actions and projects. For example, in Tanzania, Public Agencies have reasonable budgets to run their activities but NMAs and Ministries have limited budgets. Also, NMAs have high knowledge level compared to Public Agencies.

Table 1: Minimum and maximum values set for organizational attributes (range 0-10).

s/n	Attribute	Public agencies		NMAs		Ministries	
		Min	Max	Min	Max	Min	Max
1	Budget	8	10	4	8	2	5
2	Technology level	3	7	3	7	2	5
3	Standards and procedures	1	6	1	7	0	6
4	Authorization	8	8	2	2	0	0
5	Culture	2	5	3	6	2	6
6	Data sharing	5	7	5	7	2	7
7	Knowledge level	2	5	8	9	2	8
8	Spatial knowledge index	1		10		5	
9	Data availability	1	8	4	8	3	8

Each organization is rewarded for carrying out a project successfully within the specified time (months in this case) under the current constraints indicated in Table 2. Constraints are the limiting factors for attribute improvement that ranged from 0 to 10 and were estimated based on field work and previous work. For example, the organization can only proceed to perform project 1 if the values on knowledge level, culture, capital, technology are greater than three. The rewards were the estimates of how a project will improve the attributes of an organization and ranged from 0.0 to 1.0 as listed in Table 2. The rewards are obtained at the end of each project.

Table 2: Constraints and rewards from projects for improving organizational attributes.

	Attribute	Project 1 (60)		Project 2 (12)		Project 3 (12)		Project 4 (60)	
		Cons	Reward	Cons	Reward	Cons	Reward	Cons	Reward
1	Knowledge level	> 3	+ 0.1	> 5	+ 0.1	> 5	+ 0.1	> 4	+ 0.1
2	Culture	> 3		> 5	+ 0.1	> 3	+ 0.1	> 2	+ 0.1
3	Standard and procedure	> 4		> 2			+ 1	> 4	+ 0.1
4	Technology level	> 3		> 5				> 3	
5	Capital	> 3	+ 0.05		+ 0.1	> 1		> 2	
6	Budget		- 0.5		- 0.5		- 0.5		- 0.5
7	Data sharing		+ 0.1		+ 1		+ 0.5		+ 0.1
8	Data availability		+ 1	> 1	+ 0.1		+ 0.1	> 3	+ 0.1

Some organizations were lacking basic capacity for carrying out projects. This occurs since different organizations had different roles towards SDI related activities. In such cases, there were options for carrying out actions (see section 2.3.2) in order to improve the attributes and therefore be capable to perform projects. A criterion was given that if an organization is required to hire a private company in order to perform projects. Then the organization must have a minimum attributes value of 3. After carrying out the respective action, the organization attributes were improved based on rewards shown in Table 3. For example, by conducting Action 1: Training, an organization receives +1 point as a reward for improved knowledge level, +1 point reward for culturing, and -0.1 point for budget. Also, by conducting Action 2: Employment, an organization receives +1 point reward for knowledge level improvement, +0.1 point reward for culture, and -0.1 point for budget. Minus point is given to the budget because the budget is decreased by spending money.

Table 3: Points for rewards from actions for improving organizational attributes.

sn	**Attributes**	**Act. 1**	**Act. 2**	**Act. 3**	**Act. 4**	**Act. 5**	**Act. 6**
1	Knowledge level	+ 1	+ 1	+ 0.1	+ 0.1		
2	Culture	+ 1	+ 0.1	+ 0.1	+ 1		
3	Standard and procedure						
4	Technology level			+ 1			
5	Capital					+ 50	
6	Budget	- 0.1	- 0.1	– 0.15	– 0.1		
7	Data sharing						
8	Data availability			+ 0.2			+ 0.1

2.3.5. Sub-models

The following sub models are part of the processes described in “state variables and scales”, in section 2.3.2 and “process overview and scheduling” in section 2.3.3 The first sub-model involves the procedure used by organization for selecting a private company, based on scoring and a decision to hire. The scoring is based on the following attributes; surplus knowledge, surplus technology, reputation, price coefficient, and support from the government. The equation is as follows:

$$S = \frac{(a - a_{reg}) + (b - b_{req}) + c + d}{e} \qquad [3]$$

where S = selection score, a = technology and tools, b = knowledge on spatial data, c = reputation, d = governmental support and e = price coefficient.

The second sub-model involves the procedure of grouping together similar organizations and assigning related attributes for individuals. In order to examine the individual agents’ effects when interacting with each other and with the projects and actions, the organizations are grouped in three levels as indicated in Figure 4. The links are used to monitor agent’s relationships so that they don’t perform parallel projects or actions. The aim is to help investigating the agents’ activities for projects and actions, and come out with the shortest route taken by agents. The shortest route can represent the best option to follow when deciding on activities for developing an SDI.

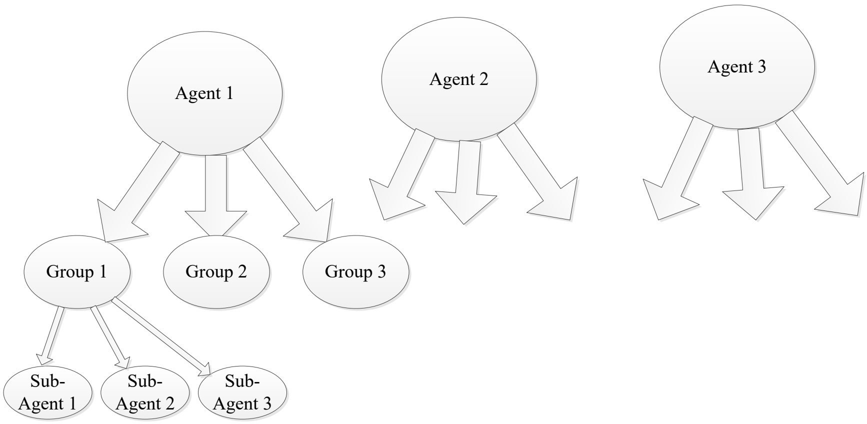

Figure 4: Grouping of agents.

2.4. Evaluation of the model

The model was checked and evaluated in order to test its performance using the parameters described below. The first parameter was the minimum time for an organization to finish projects and actions to reach its target. The second was the minimum cost for the organization to gain the required level of attributes. The third was the minimum number of activities for the organization to reach its goals, and the forth was the summation or the combination of the above parameters. Since the parameters have different units and domains, they are normalized from 0 to 1 by the equation:

$$x^1 = \left(\frac{x_{max} - x_n}{x_{max} - x_{min}}\right) \quad [4]$$

where x_{max} is the maximum value attained, x_n is the value for the parameter, and x_{min} is the minimum value.

2.4.1. Performance evaluation and SDI strategic planning

Performance evaluation for organizations was done where individual agents were made to select projects and actions either randomly or by using specific requirements. After the model was run, and the requirements reached the threshold (i.e. when an organisation gains enough attributes and fulfils the objectives), the different paths taken by agents were established. The performance evaluation method was important for strategic planning. The parameters were changed several times during model simulation and the researchers observed different scenarios. The best path is the one with minimum time, few activities, and minimum cost. The results that shows the performance evaluation in terms of time spent (months), activities involved, cost used and index for Public agencies, NMAs and the Ministries are presented in Appendix II.

In the model, all organizations were assigned capital and budgets proportional to their roles and also there were costs associated with projects and actions. The cost indicated in the appendices is the amount used by an organization while performing projects and actions in order to achieve the given objectives. Also, Index is the combination of the three basic parameters (time, activities and costs) normalized according to the parameter distribution.

3. Results and discussion

Successful SDI implementation occurs when there is a strong partnership among organizations involved in the SDI development, and the main objectives are achieved. The organizations as agents were assigned projects and actions based on their roles. Individual characteristics were captured in the model initialization. In the following sub-sections, results of the model growth and priority tables are presented.

3.1. Agent-based Model growth

"Data availability" and "standards, and data sharing" are two main objectives in our ABM simulation. Data availability output is the summation of reward levels of organizations that selected and performed projects on spatial data production and geodatabases. The rewards are the gain or improvement in attributes for the organization to be able to carry out SDI projects efficiently. Figure 5 shows the summation of data availability for fifteen years. National Mapping Agency (NMA) reaches the target after approximately 100 months, or around 8 years.

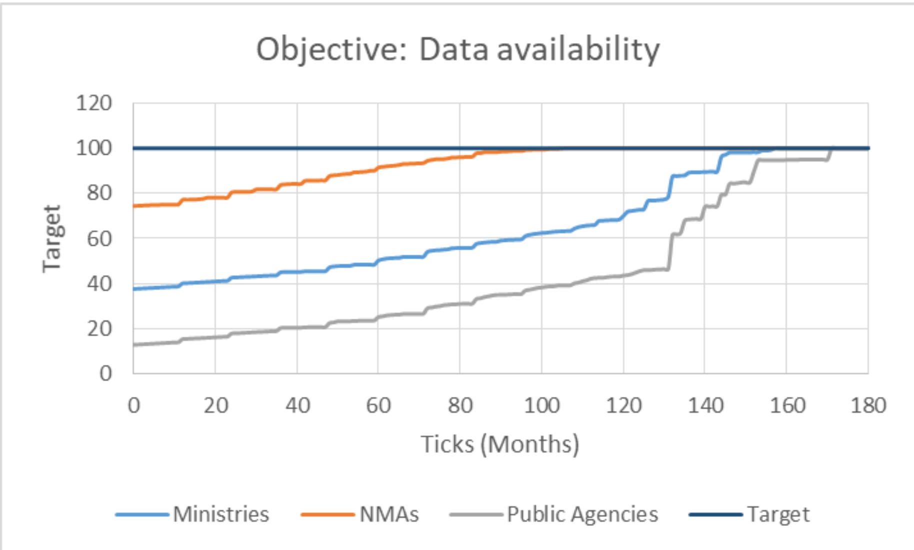

Figure 5: Results from Data availability objective.

In order for SDI to function, spatial data have to be generated. Creating a geodatabase, which means establishing databases for spatial data, is a necessity. Since all captured data will be stored and managed in the databases. NMAs have knowledgeable staff, good technology, inadequate budgets, and good standards and therefore reaches target in the shortest time (Fig. 5), Ministry departments reach the target after approximately 160 months, or 14 years. They have different roles related to SDI, with fewer knowledgeable staff, limited technologies and budgets, and relatively poor standards. Public agencies reach targets approximately in 180 months, or 15 years. Also they play different roles in relation to SDI, having fewer knowledgeable staff, limited technologies and poor standards, but enough budgets.

Standards and data sharing in spatial data science help to facilitate and coordinate the exchange and sharing of spatial data between stakeholders in the spatial data community. As illustrated in Figure 6, NMAs reach the target for standards and data sharing after approximately 85 months, or 7 years. Public agencies reach targets approximately in 110 months, or 9 years. Ministry departments reach target after approximately 135 months, or 12 years.

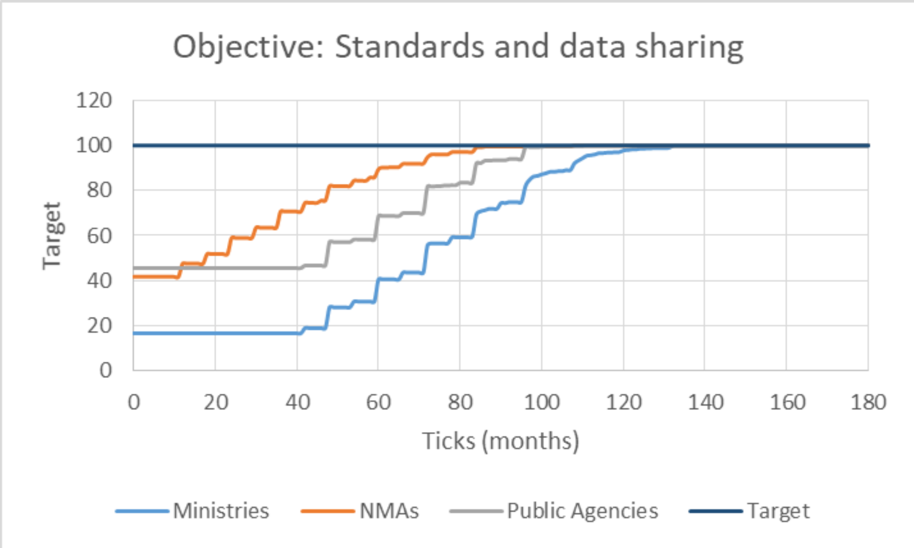

Figure 6: Results from Standards and data sharing.

According to the results shown in Figure 6, NMAs reach the target for standards and data sharing in shortest time. As compared to other agents, the NMAs have knowledgeable staff, good technology, limited budgets, and good standards. Public agencies reach the targets in approximately 9 years, which can be attributed to fewer knowledgeable staff, limited technologies and poor standards, but enough budgets. Ministry departments reach the target after approximately 12 years, since they have fewer knowledgeable staff, inadequate technologies, lack of budgets, and poor standards.

3.2. Priority tables for spatial data production, standards, and spatial data sharing

Agents in the model have different attributes according to the roles of organizations within the groups, as well as rules depending on the interactions in the model. In the model simulation, all activities were recorded. The agents within the groups were prioritizing attributes to be improved in order for them to carry out projects. The priority tables (Table 4 & 5) show the number of times an attribute was used for an agent in a group until it reached the targets for the objectives spatial data production and standards and spatial data sharing. Different groups have different roles and targets, and the numbers in the tables reflect the needs for each group.

In Table 4, one can observe that capital and data availability for the ministries were the mostly requested attributes compared to others. For public agencies, data availability was mostly requested followed by the capital. Public agencies were assigned little values for many attributes because in their policies, SDI issues were very little or none. Therefore they lacked basic attributes such as knowledge, culture and technology to carry-out projects of which more funds were needed to hire PSC. Ministry departments had more scores than other groups. For NMAs, standards were more requested followed by availability. On the other hand, public agencies had no problem with technology.

Table 4: Number of times an attribute was used for objective 1 - Spatial data production.

Attribute	Public agencies	NMAs	Ministries
Capital:	169	46	3936
Data Availability:	254	69	264
Standards:	49	103	159
Technology:	0	18	62
Knowledge:	25	0	62

Regarding standards and spatial data sharing presented in Table 5, the government ministries attribute knowledge was more requested than other, followed by capital, culture, and standards. NMAs attribute capital was more requested followed by awareness and culture of data sharing. Public agencies attribute knowledge was most requested, followed by culture and standards. Ministry departments had more requests than other agents in other groups.

Table 5: Number of times an attribute was used for objective 2 - Standards and spatial data sharing.

Attribute	Public agencies	NMAs	Ministries
Knowledge:	466	0	1171
Capital:	27	112	1055
Culture:	206	91	486
Standards:	85	86	206
Sharing:	14	19	71
Technology:	7	37	22

Generally, priorities for spatial data production, standards and data sharing (Tables 4 & 5) showed that ministry departments have limited resources in terms of capital, knowledge, standards and culture of data sharing. Public agencies are mostly autonomous, which means they can mobilize funds with little bureaucracy. They have higher technology and capital than NMAs and ministries. NMAs on the other hand, can support the development of SDI in the country (Mango, 2015). Spatial data production and standards are the activities in focus. They have knowledgeable staff, better technology for data collection, and they possess a larger spatial database but lack capital, culture and standards.

SDI is affected partly because of unequal commitment and conflicting priorities among the organizations (Giuliani et al., 2015, Gelagay, 2017). For example, according to Maphale and Moreri (2018), efforts to enhance the development of NSDI can focus on establishment of sufficient collaborations and strong coordination. For example, Tanzania lacks proper coordinating body (Hagai, 2017, Mwange et al., 2018, Ngereja et al., 2018) and this model highlights attributes of some selected organizations. Understanding the roles and functions, organizations will be better informed and make better decisions and hence come up with a more reliable strategic planning. Best coordination of NSDI requires both a reliable strategic plan and a clear vision necessary to develop and maintain political support, ensure policy integration, and inclusion of different stakeholders

(Giuliani et al., 2015, Gelagay, 2017, Atumane and Cabral, 2019, Lubida, 2019). Also a coordinating body is a key to guide on most important initiatives including creating awareness, technical support to organizations and all issues regarding training and skill development as part of capacity building in the country (Hodza et al., 2015, Käyhkö et al., 2018). Likewise Organizations with appropriate attributes can work as a producer and provider of data and services in SDI while others remain as users (Sinvula et al., 2017).

A study of the status of NSDI in Africa by Mwange et al. (2018) showed a generally slow progress for most of the countries. For instance countries including Ghana, Uganda and Kenya have NSDI draft policy in place awaiting for respective governments to approve (Makanga and Smit, 2008, Mwange et al., 2017). In Ghana, SDI related policies are in place and Land Administration Projects (LAP 1 & 2) established fundamental SDI network and data in the country However, the establishment of Kenyan Geospatial Data Centre and also the Rwanda's NSDI portal both in 2015 were some of the good progress towards development of NSDI in the Region. Namibia's SDI policy and standards as part of Namibia Statistics act was approved by the government in 2015. Later in 2016, the memorandum of understanding between the Committee of Spatial Data (CSD) and key stakeholders were signed to mark the start of Namibia SDI (Sinvula et al., 2017). In South Africa, The National Spatial Information Framework (NSIF) was established in 1997 and later the South Africa Spatial Data Infrastructure (SASDI) was founded through SASDI Act No 54 of 2003 (Siebritz and Fourie, 2015, Sinvula et al., 2017, Mwange et al., 2018, Tripathi et al., 2020).

4. Conclusion

In this study, ABM simulation was employed to better understand the SDI development process and potentially make better planning in Tanzania. The ABM was able to handle interactions of organizational attributes based on simple rules. The resulting behaviour of agents were analysed and the priority areas identified. By changing parameters and simulating the development of SDI for different scenarios, it was realized which factors should be considered with high priorities in Tanzanian SDI's strategic planning. In this way the strategic planning for SDI development will be more realistic. ABM helped to obtain a more detailed focus on attributes that will help the organizations to fulfil objectives related to SDI development. With the current trend of organizations continuously pursuing objectives making spatial data available and accessible in Tanzania, this model can increase knowledge and help the government's initiative of establishing a National Spatial Data Infrastructure (NSDI).

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