SDI planning using the system dynamics technique within a community of practice: lessons learnt from Tanzania

Ali MANSOURIAN*a, Alex LUBIDAa, Petter PILESJÖa, Ehsan ABDOLMAJIDIB and Monica LASSIB

*aGIS Center, Department of Physical Geography and Ecosystem Science, Lund University, Sölvegatan 12, 22362 Lund, Sweden; bDepartment of Research and Study Services, Lund University Library, Lund University, Helgonabacken 1, Box 3, SE-221 00 Lund, Sweden

(Received 14 March 2015; final version received 9 May 2015)

There exist major challenges in accelerating the spatial data infrastructure (SDI) planning process in the developing countries as well as advocating for politicians to support the development of SDI, due to the high complexity of SDI, lack of knowledge and experience, and limited insight in the benefits. To address these challenges, a methodology for SDI planning in Tanzania, based on the system dynamics technique and the communities of practice concept, was adopted and applied within a community consisting of experts from stakeholder organizations. The groups gathered to develop an SDI plan, while they shared their knowledge and discussed their ideas that helped their understanding of SDI. By running the system dynamics model, the development of SDI over time could be simulated that gave the planning community an insight about the future effects of today’s plans and decisions. Finally, an optimum model could be developed by refinements and improvements done with the consensus of the SDI stakeholders. This model included the components and policies that are essential for a successful SDI implementation in Tanzania and can be used as a basis for SDI planning and help to gain political support. Lessons learnt from this research were promising regarding the usability of the methodology for SDI planning in comparable countries.

Keywords: spatial data infrastructure (SDI); planning; system dynamics technique; community of practice

1. Introduction

Spatial data infrastructure (SDI) is typically defined as a set of interacting institutional, technological, human, and economic resources that are available for facilitating and coordinating the spatial data access, use, and sharing (1, 2). Since the development of SDI has been recognized as an essential requirement for sustainable development (3–7), many developing countries, including several in African, are planning the development of a national SDI. For example, in Tanzania, the urgent need of SDI for urban planning and management, agriculture, mining, and disaster management is recognized, and hence, the development of a national SDI is highly prioritized by the Prime Minister’s Office of Tanzania (8–10). However, there exist major challenges in accelerating the SDI planning process, as well as advocating for politicians to support the development of SDI:

- The current and ongoing culturing and training activities in the form of seminars and conferences are very beneficial for increasing the knowledge of SDI stakeholders about the general concept and advantages of SDI. However, SDI planning, implementation, and management require detailed knowledge in the field, which is limited for the SDI stakeholders. The complexity of SDI, in terms of the variety of affecting factors and the interactions between the factors, makes SDI planning a very complicated task in developing countries.
- SDI is a cooperative effort, which requires effective collaboration between different organizations, who are SDI stakeholders. Agreeing on an SDI development plan is a fundamental requirement for an effective and successful collaboration. However, the complexity of SDI often results in that it gets differently understood by different organizations. As a result, the different approaches and plans, which are not compatible and/or comprehensive enough, are often proposed for the SDI development, making it difficult and sometimes impossible to agree on a common SDI plan.
- SDI is still a new concept for decision-makers and politicians in African countries. At the same time, these countries have generally limited financial resources for spatial data activities, due to the relatively weak economic conditions. These factors, together with lack of clear benefits of the outcomes of implementing the SDI plan, sometimes make governments reluctant to support and invest on the development of SDI.

To address the above issues, within the context of a research project funded by the Swedish International Development Cooperation Agency, inspired by the work...
of Mansourian and Abdolmajidi (11), a methodology for SDI planning in Tanzania based on the system dynamics technique and the communities of practice concept was adopted and applied within a community consisting of representatives of stakeholder organizations. This methodology helps in developing an SDI plan with the collaboration of all the SDI stakeholders, which facilitates receiving their approval of the plan. At the same time, learning occurs as the community works together during the SDI planning, which increases the knowledge of planners (representatives of stakeholders) on the complexity of SDI including details that should be considered. The method also provides an outlook of the future status of SDI, its progress and its advantages, by implementing a specific plan. It facilitates receiving the support of politicians for the development of the plan. Lessons learnt from this research were promising regarding the usability of the methodology for SDI planning in comparable countries.

2. Background

2.1. Spatial data infrastructure (SDI)

The growing need to organize data across different disciplines and organizations and the need to create a multi-participant and decision-supported environment have resulted in the concept of SDI. SDI is an initiative intended to create an environment that will enable a wide variety of users to access, retrieve, and disseminate spatial data in an easy and secure way. In principle, SDIs allow the widespread sharing of data, which are extremely useful as it allows the users to save resources, time, and effort in acquiring new sets of data, avoiding duplication of expenses associated with generation and maintenance of data as well as their integration with other datasets. SDI is dynamic and hierarchical in nature and consists of various interacting components (1). In addition, a variety of institutional, technological, economic, and political factors affect the development of SDI, and these factors yield feedback and interactions over time. In brief, SDI is a complex, adaptive system (11–13) that requires a long-term process of implementation.

To cope with the complexity of the SDI environment, researchers and practitioners have developed a variety of models to gain better insight into its nature and behavior. Most models concentrate on one specific aspect of SDI. The general model of SDI was developed by Rajabifard et al. (1) and includes the core components (people, data, policy, standard, and accessing networks) and their mutual relationships. These authors also developed a model of SDI hierarchy, which is made up of inter-connected SDIs at organizational, local, state, national, regional (multi-national), and global levels. The models are fundamental as they clarify the basic concept and nature of SDIs. They are very beneficial for the coordinating agencies and the SDI stakeholders for the development of SDIs, and also for researchers to construct new, improved, practical, and functional models.

Different studies have been conducted to identify the factors affecting SDI and to develop general data-sharing models, based on these factors (see Refs. (14–16)). These models are generally used to strengthen the partnerships between organizations. The Commission on Geoinformation Infrastructures and the Standards of the International Cartographic Association (ICA) has defined the conceptual models of SDIs (17, 18). ICA has presented SDI models from the enterprise, information, and computational viewpoints based on the ISO Reference Model for Open Distributed Processing standard. The model, which is developed from a computational viewpoint (18), identifies the main computational objects of an SDI and their interfaces, modeled using Unified Modeling Language component diagrams.

The above-mentioned modeling efforts do not address the direct modeling and simulation of the development process of an SDI over time. To fill this gap, Mansourian and Abdolmajidi (11) proposed a simulation model for the development of SDIs using the system dynamics technique. They showed that such a simulation model helps SDI coordinators and managers to simulate the development of SDI over time based on different scenarios and hence to get an insight into the future effects of today’s decisions and policies. Such an insight helps to make a more reliable plan for the development of SDI.

2.2. System dynamic technique for SDI modeling

In today’s world, there is a variety of complex systems, highlighting a significant need for tools and processes that can help to model these systems, understand their complexity, and design better operating policies (19). The system dynamics technique is a method for modeling and managing feedback systems that are complex, dynamic, and nonlinear in time. The technique can enhance the understanding of a complex system reducing the development cost and increasing the reliability of the system development. A system dynamics model allows the modeler to reuse previously built components in a new system and aids in implementing the required changes (20, 21).

The technique has been used to model numerous complex systems, such as urban, industrial, and ecological systems (22–25), as well as information technology (26, 27), to gain insight into the characteristics of their behavior. Gaining such insight may simply be motivated by an intellectual desire for deeper understanding, or by a variety of more practical and specific reasons such as providing a basis for decisions relating to the control, management, acquisition, or transformation of the system under investigation (28).

Feedback loops are the building blocks of system dynamics. A feedback loop is a structure within which a decision variable (flow) controls an action that is integrated into the system to generate a system state.
Information pertaining to the state is then fed back to the decision variable, which in turn is used to control the flows. Two kinds of feedback loops comprise all complex behaviors of a system (19, 29):

1. Positive feedback loop. Positive loops are self-reinforcing and tend to amplify whatever is happening in the system.
2. Negative feedback loop. Negative loops are self-correcting and tend to counteract and oppose changes. An increase in one parameter causes the other parameter to increase, which then decreases the first parameter.

A feedback loop is composed of two kinds of variables:

1. State. State is an accumulation characteristic of the state of the system that generates the information upon which decisions and actions are based. A state variable is altered by inflows and outflows and is represented by a rectangle in a model.
2. Flow. Flow is a variable that changes a state over a period of time. Flow variables are of two types: An inflow increases a state and an outflow depletes a state. In short, a flow is a statement of system policies that determines how information about the system is translated into action(s).

There are some other elements and concepts, such as auxiliary variables, constants, time delay, and growth engines which are used in the system dynamics modeling (see Ref. (29) by Sterman for more information). Among them, a growth engine is a positive feedback loop which makes the system grow with a small initial force (eminently if there is no limitation).

The system dynamics model can be used as a virtual world to simulate real situations. Virtual worlds are formal models, simulations, or “microworlds” in which decision-makers can improve decision-making skills, conduct experiments, and act out situations (19). The development of an SDI is a long-term process requiring large financial investments. Moreover, due to its complex nature and the variety of influencing factors, several strategies and decisions seem feasible in the development of an SDI. However, the main challenge is to make proper decisions during the design process of an SDI. Then, repeatedly simulating the development process of an SDI in a virtual world under different strategies allows the SDI developers to conduct controlled experiments for the design and adopt propitious decisions. As the system dynamics technique can model many characteristics of an SDI as a complex adaptive system, it would be beneficial to use such techniques for better understanding the SDI development behavior (11).

2.3. Communities of practice

The community of practice (30) concept can be used to understand and describe how members of a community, often in a professional or organizational setting, share knowledge and learn in collaboration. The concept started as a way of describing apprenticeship, meaning novices learning from experts by observing and practicing a profession (30). The definition of communities of practices used in this article is as follows:

inter- or intra-organizational, often geographically dispersed, groups of people that have a long-term orientation on knowledge sharing or knowledge creating activities. The groups have their own identity and focus on their knowledge processes around a certain practice, i.e. a professional discipline, skill or topic (page 14 in Ref. (31)).

In the context of the study reported here, the groups consist of experts from stakeholder organizations across Tanzania, gathered to develop a common understanding of SDI. It can be characterized as a formal expert community (31).

Individual community members may be experts in one area and novices in other areas, and therefore, a vital aspect of communities of practice is that members learn together. Communities of practice have three main characteristics: A domain of interest that defines its identity, a community of members who interacts and learns in collaboration, and a shared practice including how to define, talk about and address problems, ways of solving problems and of sharing experiences (32).

In order for a community to function well, the community needs to establish and maintain a common ground (33), meaning that the community members share mutual beliefs, knowledge, and vocabulary (34). Different fields of expertise may use different definitions of the same term, and when people from different fields converge in a community, a common ground needs to be established. For example, the connotations for the term operation include mathematical, military, and surgical operations, which can cause misunderstandings if not defined and negotiated within the community. The necessity of common ground is important for at least two additional reasons: for sharing the community’s knowledge with other communities and organizations, and “for developing a shared understanding of complex systems of ideas that the community develops” (page 86 in Ref. (35)). A community that practices self-awareness, for example, by discussing how their beliefs and vocabulary have changed over time, aids to keep the community progressing as the starting point and the history of the community is reflected upon (34).

3. Case study and methodology

3.1. Case study

The United Republic of Tanzania is situated in East Africa, with a total area of about 947,300 km. It is
located on the east coast between latitudes 1° and 12° South and longitudes 29°–41° East. It is bordered by Uganda and Kenya to the North, Indian Ocean to the East, Mozambique, Malawi and Zambia to the South, and Democratic Republic of Congo, Burundi and Rwanda to the West. According to the 2012 census, Tanzania had a population of 45 million people (36).

United Republic of Tanzania was formed in 1964 through the union of Tanganyika and Zanzibar. Administratively, it is divided into 30 regions, 25 on the mainland and 5 on the Zanzibar islands. In total, there are 117 urban and district local authorities and around 12,500 villages in the country. The main sectors which contribute to GDP are agriculture, tourism, and mining industry. Agriculture is the main sector and accounts for about one-third of GDP, employs 75% of the population, and provides 85% of exports. Tourism ranks as the second highest foreign exchange earner after agriculture.

In Tanzania, a policy proposal for National SDI is in place since 2007 (37), being prepared by the National Steering committee which has been in place since 2003 (38–40). The coordination of the Tanzania NSDI is currently under the National Bureau of Statistics (NBS) and has the establishment initiative in its Strategic and Business plans 2003/2004–2005/2006 (40, 41). NBS organized their latest workshop on TNSDI in November 2013, for the purpose of obtaining views from stakeholders, finalizing, and making a plan ready for submission to the government as it was planned in the Tanzania Statistical Master plan 2009/2010–2013/2014 (42). The policy has to be approved in the parliament before it is implemented. This includes the policies on land management and ICT, and the availability of fundamental spatial datasets (10, 43, 44).

### 3.2. Methodology

The methodology used in this study is based on a mixed methods approach (45), in which the methods from different methodological paradigms are employed. The aim of this approach is to lead the SDI development by solving a problem at hand, i.e. developing an SDI plan and at the same time creating opportunities for sharing expertise and learning among the community.

The development of the SDI plan was conducted in two main stages. At the first stage, the current status of SDI and/or spatial data activities in Tanzania was modeled by the community of stakeholder representatives, using the system dynamics technique. The model and the whole modeling process, including developing, negotiating, and coming to an agreement on it, provided the SDI planners with insights about current obstacles, weaknesses, and issues for the development of SDI. By running the system dynamics model, they also gained insights into the future progress and growth of SDI in the country, provided that the existing situation and policies are followed. At the initial state, it was observed that good progress on all aspects of SDI cannot be expected. At the second stage, the developed model was refined and improved upon by the community, in a way to show a reasonable and acceptable SDI progress over time. This new model included the components, activities, and policies that are essential for a successful SDI implementation in Tanzania and can be used as a basis for SDI planning in the country. Different steps, which were followed at each stage, are described below.

Two groups of experts were established: one with experts from the academic sector (EAS) and one with experts from executive organizations (EEO). Their work constitutes the early stages of community development, including building a case for membership and launching the community, and sharing ideas and practices among members (32). EAS included academic staff and researchers with backgrounds in different aspects of spatial information sciences and social sciences from Lund University, Sweden and University of Dar es Salaam, Tanzania. A subgroup of EAS – the research team – led the scientific work of the study. EEO mainly consisted of people who represented the SDI stakeholders in the Tanzanian SDI steering Committee. EEO members had different range of expertise and educational level as well as organizational cultures and membership in other communities of practice, all coming together in this context.

Then, through a questionnaire survey, the current status of Tanzania from an SDI perspective was studied and evaluated. Three types of questionnaires were prepared targeting three groups of people in the organizations, including experts in spatial data management, general staff, and managers. The questionnaires became available both online and printed. The first target group expected to provide information about the current status of technical, technological, and social aspects of spatial data in the organizations. The second group targeted potential users who could provide information about the current status of spatial data activities and flows as well as the requirements from a user perspective. The third group was managers and decision-makers who could provide information about the current institutional issues of spatial data activities from a managerial perspective. EEO and EAS members were provided with required guidelines of the aim of the questions, how the questionnaires should be filled, and then requested to take part in the survey. Thirty-two organizations were requested to answer the questionnaires. Of them, twenty-three organizations responded. The questionnaires were distributed to 87 individuals in the organizations and 57 individuals (66%) responded. The questionnaires involved both open- and close-ended questions, of both qualitative and quantitative in nature. The survey functioned as a boundary object between the community and other communities of practice to which the members belonged. The distribution of the survey can further be seen as a boundary interaction, which could initiate interactions about SDI and related topics with the other communities.
The questionnaires were then collected and analyzed by the research team. Complementary interviews were also conducted with some experts, involved in SDI and spatial data activities in their own organization, to get a better understanding of the current situation. The results were presented to the EEO and EAS. The presentation of the questionnaires aided in identifying the existing activities, knowledge, and knowledge gaps among the community (32), which sparked a learning process based on defining, redefining and negotiating ideas, assumptions, and terminology. This learning process continued throughout the subsequent steps, in developing the SDI plan.

Based on the results of the survey, a system dynamic model was developed by the research team, using state-flow diagrams. This model presented the current status of the SDI in Tanzania, developing a common ground among the group members. The model included the main components of the current status and future plans according to the national SDI draft proposal and the Tanzania Statistical Master Plan 2009/10–2013/14 (37, 42).

Adopting the Delphi approach (46) in the context of collaborative activities within the groups of experts, the model and its components were presented to the EEO and EAS and then they were requested to contribute in refining the model (47) for a similar approach to data collection and analysis. The final model simulated and demonstrated how SDI can develop over time in Tanzania, if the situation will not be subjected to major changes. It also showed the interaction of the SDI affecting factors, and hence the complexity of the SDI as well as existing shortages and bottlenecks for the development of SDI in Tanzania. The overall output at this stage also helped in increasing the knowledge of the members about the complexity of SDI and the factors that should be considered when developing SDI.

Thus, as a result of the cooperation between EEO and EAS, and by adopting the Delphi approach, the SDI model presenting the current situation was finalized. It was then developed to an optimum model for the development of SDI in Tanzania. The changes were then concentrated on removing the bottle necks and the main issues/challenges, as well as creating growth engines to facilitate the development of SDI. This final model also showed the future progress of the SDI, based on the current design.

4. Modeling the current status of SDI in Tanzania

Based on the outcomes of the questionnaire survey, the factors which play the main role in the current status of Tanzania SDI were identified. Second, a dynamic hypothesis was constructed by identifying and analyzing the relationships among these factors. A dynamic hypothesis is a working theory on how a problem has arisen and guides the modeling effort by making the modeler and his or her clients to focus on certain structures. The dynamic hypothesis model was developed using state-flow diagrams in the NetLogo software¹ authored by Wilensky (48) (Figure 1). Then, at the third step, the relationships between the factors were defined numerically. When a primary model was developed by the research team, at the fourth step, this was refined collaboratively together with the EEO and EAS. In this step, the model was simulated and evaluated relative to the current status of SDI in Tanzania: if the model did not satisfy (present and simulate) the current status, the previous steps were repeated to revise/refine the model.

4.1. The state-flow diagram of the current status of SDI

Figure 1 shows the state-flow diagram presenting the current status of SDI in Tanzania. Different affecting factors were considered as state, auxiliary or flow variables depending on their role in the model. Seventeen factors were modeled as the state variables:

• Quality of standards: Limited spatial data standards are available in Tanzania. However, they have been mainly developed by international organizations that have produced topographic and different types of thematic maps for the governmental organizations. For SDI, the quality of standard is mainly measured by the level of satisfaction of SDI stakeholders (producers and users) and also their compliances with international standards such as ISO that are not being well attended in Tanzania SDI.

• Participating organizations: The number of organizations participating in the development of SDI determines the size of data sharing, the quality of standards, etc. The participation of an organization depends on technological, cultural, skill, and financial readiness/capacity of the organization.

• SDI awareness: Being aware of the concept and advantages of SDI is very important for receiving the support of politicians in the development of SDI. It is also important to increase the willingness of organizations to participate in the development of SDI.

• Technology: Accessing networks including active Geoportals, spatial web services, and spatial data servers is an essential requirement for online spatial data searching, accessing, and sharing. This requires availability of minimum acceptable technological infrastructures, especially IT, at the national level and within organizations.

• Skill formation: SDI development is a complicated task which requires skilled people to play a major role in different activities including SDI planning, creating and maintaining databases and web services, using and diffusing spatial data in daily activities of the organizations, etc. Training the existing employers and activating universities to produce required skills are two main activities for human resource development and skill formation.
Figure 1. The state-flow diagram, modeling the current status of SDI in Tanzania.
The latter one highlights the important role of universities in the development of SDI in Tanzania.

*Training employees:* Training the current staff, as part of human resource development, to get the knowledge of spatial data management can fill the gap of spatial data experts, especially for activities such as data production and updating, creation of geodatabases, etc.

*Hiring experts:* Hiring educated spatial data experts and involving them in spatial data activities of organizations are essential in filling the gap of experts for spatial data activities.

*Subcontract:* Outsourcing some spatial data activities/projects to private sector is part of the public private partnership (PPP).

*Available data:* The data which are produced by organizations, as a result of their daily activities or special data production projects, are counted as available data. The quality of the data is dependent on the quality of standards and the skill and experience of people/companies producing the data. These data become old after a while, depending on the type of datasets.

*Duplicated efforts:* As the name indicates duplicated and/or parallel activities of organizations in producing the same type of data leads to waste of financial resources.

*Data management:* This is about management of the available data in a good way, e.g. spatial databases with metadata linked to them and dissemination of the data.

*Archive:* Available data should be archived, since they are still usable as historical data in the future.

*Income:* In the context of clear financial policies one can earn income from an SDI, through selling spatial data and spatial data services. This money can be used for further development of SDI.

*Actual budget:* This is the total budget which is specified for the development of SDI.

*Culturing:* Culturing and increasing the general knowledge of SDI stakeholders are essential parts of SDI.

*Fund for technology:* Increasing technological level of organizations requires financial resources.

*Budget for capacity building:* This is the budget which is assigned for human resource development.

Forty factors, such as partnership, training costs, and data quality, were considered as the auxiliary variables, and thirty-three factors were considered as the flow variables.

The state-flow diagram presenting the current status of Tanzania SDI consists of several positive and negative feedback loops (Figure 1). Below we give the explanation of one of the loops as an example. Currently, map productions as well as creating database and web services are among the main SDI activities, which are subcontracted (subcontract SDI) to private companies. These are generally foreign companies carrying out extensive map production and other web-related projects, due to the limited capabilities of the Tanzanian companies in terms of skill and technology. Map production increases the availability of data (available data). At the same time, lack of coordination results in (increases) duplicated efforts in data production (annual duplication cost), which is a waste of money. Availability of the data requires more management of the data (data managed). Having more data, one can expect more income, as a result of selling them to the users. Such income is used for other SDI activities such as a better data management.

Examining a state-flow diagram, one can realize strength points (e.g. data availability in our example loop) and weak points (e.g. duplicated of efforts) in the current SDI system of Tanzania. The system dynamics model helps to realize these points and consider them for the development of the refined SDI model. In addition, there are some points which were regarded as strong positive and effective aspects of the current SDI plan before, but the system dynamics model, which includes numerical values and relationships for the variables and between the variables, reveals that they are not as strong and positive as they were assumed. For example, the income from selling spatial data was assumed to be a considerable financial resource for supporting SDI activities in Tanzania. However, the model (Figure 1) showed that the SDI income from selling available data is too small in comparison with the high expenses of other SDI activities including spatial data production. This means that one cannot count on this income as a considerable financial input for supporting even a small portion of SDI activities in Tanzania.

By further investigation of the current SDI model, developed using the state-flow diagrams, one can also realize some important factors which have been neglected in the current SDI plan, but will definitely affect the development of SDI in the country. For example, while the country is lacking proper local (Tanzanian) companies (relevant to spatial information sciences) to participate in the development of SDI, the current plan neglects supporting and strengthening the private sector and hence the establishment of PPP, which is proven to be essential for the development of SDI. Last but not least, the model shows that the current SDI system in Tanzania has no growth engine, by which the system can survive and grow independently after a while.

The model was run to demonstrate the progress of SDI and its individual factors over time. Figure 2 shows the progress and the growth of SDI awareness, data quality, and quality of standards in a ten-year time period, as examples. As the figure illustrates, with the current low investment on SDI awareness activities as well as limited availability of SDI experts, Tanzania cannot expect a good progress on this factor. The quality of standards shows a similar trend due to the lack of proper
organization for developing spatial data standards, based on the users’ requirements. Data quality cannot reach an acceptable level (closer to 100%) in the ten-year period, since data are not produced based on users’ required standards.

Figure 3, on the other hand, illustrates a good progress trend on technological preparedness of organizations within the next ten years, in terms of availability of IT infrastructures such as computers, databases, networks, and data collection tools such as GPS for spatial data management and sharing. This is because of the large ongoing investment of Tanzania in developing IT infrastructure as well as the focus of spatial data sector (e.g. mapping or GIS departments) of organizations on buying tools (hardware and software) for the collection and the management of spatial data.

In order to demonstrate the general progress of SDI development, an SDI growth index was designed as a function of six factors: SDI awareness, technology preparedness, level of partnership, data quality, quality of standards, and level of skills of personnel working in SDI. These factors have values normalized in the range from 0 to 1, and when running the model at any tick/time, the average value out of them is used.

Figure 4 shows the expected general growth trend of SDI in Tanzania, within a ten-year time period. As the figure illustrates, if the development of SDI continues based on the current situation, a 42% progress is expected and then the SDI will not grow further. This progress is mainly relevant to the data production and creating technological infrastructures, as mentioned earlier. However, no more progress can be expected because of the improper attention on the other SDI components.

4.2. Validation of the model

In order to demonstrate the validity and reliability of the SDI model describing the current status of Tanzania, the tests described below were conducted. These are the tests which have been developed and proposed by other system dynamics modelers (29). The tests were mainly conducted by EAS and presented to EEO.

(1) Boundary adequacy: This test is for investigating whether important concepts for addressing the problem are endogenous to the model. For the development of the SDI model, all the main factors affecting the development of SDI in Tanzania where identified through a questionnaire survey and were then verified by EEO and EAS. The general casual-loop diagram (Figure 5) of the model shows that all the relationships among the elements are endogenous in the model. Therefore, the SDI model developed by the state-flow diagram passes the boundary adequacy test.

(2) Structure assessment: This test, which is based on partial model tests, is used to validate the rationality of the decision rules in capturing the behavior of the actors in the system. A partial test is administered by releasing a certain type of disturbance during the simulation, e.g. a step change to a variable. Several tests were conducted, all of which were successfully passed by the model.

(3) Extreme conditions: Extreme conditions may never happen in reality. However, a model should have a logical behavior, even when its input variables take on extreme values. Two extreme conditions were applied to the SDI model: Initial values of the states were set to zero and then they were set to the maximum possible magnitude; in both cases, the model had a logical behavior.
(4) Parameter assessment: The value of the parameters must be consistent with relevant numerical knowledge of the system. Such consistence can be assures by determining the parameter values based on the experts’ opinion. Because the SDI model of Tanzania has been developed based on the experts’ opinion, then the model can be considered valid with respect to this test.

(5) Behavior reproduction: A developed SDI model should reproduce the behavior of the real world. For this test, the model was fed with the initial values from the last seven years and then the model was run. The state values for the present time were determined by the model and were compared with the real values. The differences were either negligible (small) or could be interpreted. Hence, the test was passed.

(6) Sensitivity analysis: This test is to vary the constant parameters of the model and observe how the behavior changes. In general, it is impossible to conduct comprehensive sensitive analysis in complex systems, because it would require testing all combinations of assumptions over their plausible range of uncertainty. Therefore, for testing the sensitivity of the SDI model, the uncertainty in a few factors were considered and tested. The result was that no sensitivity was exhibited on the behavior of the model.

Based on the SDI model describing the current status of SDI as well as its future situation, if the current policies are followed, EAS and EEO could realize the issues with the current status of SDI. Having such important understanding, the current model was modified in order to resolve the issues and to produce an optimum model for the development of SDI in Tanzania.

5. Development of an optimum SDI development model

To develop an optimum model for the development of SDI in Tanzania, the SDI model presenting the current situation was modified. The modification included as follows:

- Adding new factors to the model: The model presenting the current status of SDI showed that some important factors are neglected in the current SDI status of Tanzania. These factors were added to the model, as state, flow or auxiliary variables, to prepare an optimum model. The factors are relevant to the following: the clarification of the custodianship of the datasets, strengthening and supporting local experts and private sectors in the field of spatial information sciences, strengthening PPP, making SDI a self-standing and self-supporting system, and clarifying the role and the characteristics of Tanzanian SDI coordinator.

- Defining and/or revising the relationships between the variables: While new factors were added to the model, it was required to establish the relationship and feedback loops between these new factors and other factors in the model. As a result of adding new factors and relationships, some of the existing variables in the model needed to be removed/revised and some existing relationships needed to be removed/revised.

- Defining and/or revising the existing numerical equations: By updating the variables and the relationships in the model, it was an obvious requirement to define and/or revise the numerical relationships in the model. Other types of revision in the equations were also conducted, in order to include/revise new policies and activities in the SDI development model of Tanzania.

- Revising the initial and constant values of the variables: The initial and constant values of the variables describe how the new model is going to be setup and run (being implemented and work in practice). For some variables, such as the value for quality of standards, the values were determined and set based on the current situation of SDI in Tanzania. On the other side, for other variables, such as SDI budget, the values can be set to any realistic number, by SDI planners. Setting such values includes assumptions regarding the policies for the development of SDI.

The above revisions, which demonstrated a more efficient model for SDI development in Tanzania, were applied in such a way that the implementation of the model would be viable in practice. In other words, unrealistic and imaginary suggestions, such as dedicating very high annual budgets for SDI, were avoided. In this respect, gathered information from the questionnaire survey as well as the institutional and environmental knowledge of the EEO and EAS from Tanzania was considered as the important information resources and inputs.

In the context of an iterative and collaborative approach, the model was tuned and refined to produce a final model. Figure 5 presents the suggested optimum model for the development of SDI in Tanzania. The model includes four growth engines (Figure 6), in which the positive feedback loops make the system to grow with a small initial force.

The first growth engine (Figure 6(a)) is based on the hypothesis that as the number of participants in a partnership increases, the quality of standards improves. The improvement is because the standards will satisfy the requirements of more organizations or a wider range of user groups. By increasing the quality of standards, which affects the quality of data and facilitates their integration, more organizations will be motivated to participate in the development of standards. It means an increase in the number of participating organizations in the development of SDI.
Figure 5. The state-flow diagram, modeling the SDI in Tanzania in an optimum way.
The second growth engine (Figure 6(b)) was made on the hypothesis that, by subcontracting spatial data related activities to the local (Tanzanian) companies and by supporting this sector financially, a good market in this field will be formed. Availability of such a market motivates more spatial data experts to be engaged in this market by establishing companies. It also motivates/requires more students to study in the field of spatial data sciences, and hence, the country will own more graduated experts in this field. More experts will result in more knowledge, new ideas, and more subcontracting. This helps in the development of the spatial data market in Tanzania, where the private sector also plays an important role. This growth engine is very important for the sustainability of SDI in the country.

The third growth engine (Figure 6(c)) is made based on the hypothesis that society, using local companies’ potentials, can increase the quality of the spatial data products, and also reduce the expenses. Currently, spatial data activities, mainly data production, are conducted by foreign (international) companies with high expenses (39, 49, 50). Certainly, the projects’ expenses can be reduced, if being conducted by local (internal) companies. In addition, local companies, which are established by academically trained experts, are expected to have a better understanding of the users’ requirements, in comparison with the foreign companies. That is mainly because local experts can better realize the challenges and the needs, since they have been exposed to the local environment. Other factors such as language and better communication also play an important role. Considering these factors, one can expect data products with higher quality and lower expenses and also more customers for these types of data, which better meet the users’ needs. This will result in increased income for SDI. The income can be invested on other SDI activities to be conducted by local companies.

The fourth growth engine (Figure 6(d)) is made on the hypothesis that the more number of skilled people participating in the development of SDI, the higher technical quality of standards is expected. The data, produced based on these standards, will naturally have higher quality in terms of applicability and usability to the users. Then, one can expect more interest in (and larger user groups for) these data, and this can result in an increase in income. The income can be invested in other SDI activities, where local companies may be involved. Using the potential of local companies has a positive effect on increasing the number of educated and skilled persons in the field of spatial information science, as explained in the second growth engine. Some part of the fresh skilled persons can be employed in organizations and participate in the development of SDI. Their involvement has positive effects on all technical aspects of SDI, including the quality of standards, because of their technical knowledge in the field.

5.1. Running and simulation

By running the model and simulating the development of SDI, SDI planners could get an insight into the development of SDI over time, based on the new design. Figure 7 illustrates the growth of quality of standard, data quality, and SDI awareness, based on the new plan. Over a ten-year period, a good progress is expected to occur for the first two factors. However, the progress of the third factor grows slower, which is mainly explained by the expected political changes at the high managerial levels of the organizations: new awareness efforts are required for the new managers.
Lack of qualified and experienced personnel for professional implementation and maintenance of SDI affects SDI development in Tanzania (10, 37). Skills and expertise in the SDI professional category can be improved if local experts are utilized in all stages of SDI implementation. This is consistent with the national policy on improving human resources capacity in terms of skills, knowledge, and efficient deployment (42). Skill formation, by universities, in the field of spatial information sciences has been considered in the model. Then, the trained experts will be engaged in the development of SDI in different forms, e.g. being employed, as an expert in spatial information science, in governmental organizations or private companies, or even start a private company.

Considering the above-mentioned description, the new model suggests that engagement of local private sectors in the development of SDI should be implemented gradually by replacing foreign companies with local ones. Foreign companies can however form partnership with local companies in acquiring the contracts related to SDI. Figure 8 illustrates the growth and strengthening of the local private sector in comparison with the foreign companies over a ten-year period, as another example.

Figure 9 shows the progress of SDI development over a ten-year period, measured by an SDI growth index. For determining the growth index, we used the same index as for presenting the progress of SDI development, based on the current status (see Figure 4). As Figure 9 shows, with the new design, Tanzania can expect a 67% progress over 10 years, while the system will continue growing. This is based on the initial values which have been set for individual variables (SDI affecting factor). By changing the variables’ values (policies), SDI planners could obtain the estimations on the future status of SDI, as a result of today’s policies. This could help them to select the optimum plan and policy for the development of SDI.

### 5.2. Validation of the model

To validate the developed SDI model five tests, including the boundary adequacy, the structure assessment, the extreme conditions, the parameter assessment, and the sensitivity analysis test, were conducted. All the tests were passed successfully. One test, the behavior reproduction, could not be conducted because no data are available about the future of SDI in Tanzania.

### 6. Conclusion

This study suggests an integrated methodology of the community of practice and the system dynamics technique, for SDI planning in Tanzania. The system dynamics technique can model and present the complexity of SDI in terms of its main affecting factors and their interactions. The technique made it possible to present and convince EEO, who represented the SDI Steering Committee in this study, about the challenges related to the current status of national SDI, and also an optimum model for the development of a national SDI in the country. We conclude that the first challenge pertinent to model and understand the complexity of SDI can be responded using the system dynamic technique in modeling and planning SDIs.

We suggest the system dynamics technique be used in the context of community of practice. In this context, sharing the knowledge and, at the same time, learning can facilitate and improve SDI planning. EEO included members with different educational and scientific backgrounds. The members had different levels of awareness...
and knowledge about SDI, and those who had a higher knowledge had a different understanding of SDI. How to involve all these people in the planning process and at the same time increasing their knowledge and awareness on the concept of SDI was really a challenge. The community of practice helped EEO members not only to participate in the SDI planning, but also to learn and increase their knowledge of SDI. Due to the process of developing the SDI models collaboratively within the group, a common ground was established. It helped to make the member’s understanding of SDI closer to each other and to prepare an SDI plan, which was agreed by the participants. Therefore, from the experience of this study, we conclude that our suggested integrated approach is a good solution for motivating organizations to participate in SDI planning and at the same time to increase their knowledge through an indirect learning.

It was observed that the SDI model which was developed using the system dynamics technique was more tangible for decision-makers, because they could run the model and simulate the development of SDI over time. The model was also developed based on the opinions of the majority (almost all) of SDI stakeholders. Such a situation made decision-makers give higher credit to the model and the associated plan. Considering this, we conclude that our suggested approach can also partially address the challenge of motivating decision-makers in Africa to invest on SDI. Lessons learnt from this research are promising regarding the usability of the methodology for SDI planning in comparable countries.

Acknowledgments

The useful responses by officials from central and local government, academic, and private organizations in Tanzania, as well as the comments received from several other contributors, are highly appreciated.

Funding

This study is part of the project “Geodata Infrastructure Development” implemented in collaboration between University of Dar es Salaam and Lund University and funded by the Swedish International Development Cooperation Agency (SIDA) [grant number 7500051503].

Note

1. Due to the low-quality presentation of graphs in NetLogo, for the purpose of presentation in this article, the figures are redrawn using another software.

Notes on contributors

Alex Lubida is a PhD student in the GIS center, Department of Physical Geography and Ecosystem Science, Lund University, Sweden. He has a background in geomatics and currently a teaching staff and researcher at College of Engineering and Technology, University of Dar es Salaam, Tanzania. His research interests include GIS and Spatial Data Infrastructure (SDI).

Petter Pilesjö is a professor at the Department of Physical Geography and Ecosystem Science and the director of Lund University GIS Center. His research focuses on spatial data modeling. He has been working with the geographically related research projects in East Africa since the mid-1980s.

Ehsan Abdolmajidi is a PhD student at Lund University, Sweden. His MSc thesis was relevant to modeling spatial data infrastructure using the system dynamics technique. Now, his focus is more on the technical issues of SDI development such as data integration and interoperability.

Monica Lassi, PhD, is a social science researcher and librarian at Lund University. Her research and professional interests concern scientific collaboration, scholarly communication, and research infrastructures. These are tied together using a socio-technical approach to her research, in which technology and people are seen as affecting each other in the development, design, and use of tools for collaboration and research.

References

(1) Rajabifard, A.; Feehey, M.-E.F.; Williamson, I.P. Future Directions for SDI Development. Int. J. Appl. Earth Obs. Geoinformation 2002, 4 (1), 11–22.
(2) Nedovic-Budic, Z.; Pinto, J.K.; Budhathoki, N.R. SDI Effectiveness from the User Perspective. In A Multi-view Framework to Assess Spatial Data Infrastructures; Cromptoon, J., Rajabifard, A., VanLoenen, B., Fernández, T.D., Eds.; The Melbourne University Press: Melbourne, 2008; pp 273–304.
(3) Feehey, M.-E.F.; Rajabifard, A.; Williamson, I.P. Spatial Data Infrastructure Frameworks to Support Decision-making for Sustainable Development. Proceedings of the 5th Global Spatial Data Infrastructure Conference, Cartagena de Indias, Colombia, May 21–25, 2001; pp 14.
(4) FIG. The Nairobi Statement on Spatial Information for Sustainable Development; FIG: Nairobi, 2002.
(5) Williamson, I.P. SDIs – Setting the Scene. In Developing Spatial Data Infrastructures: From Concept to Reality; Williamson, I.P.; Rajabifard, A.; Feehey, M.F., Eds.; Taylor and Francis: London, 2003; pp 2–16.
(6) Paradzayi, C. Spatial Data Infrastructure as a Vehicle for Sustainable Development in Zimbabwe. In FIG Working Week and GSDI8; FIG: Cairo, 2005; pp 1–11.
(7) Ayanlade, A.; Orimoogunje, I.O.O.; Borisade, P.B. Geospatial Data Infrastructure for Sustainable Development in Sub-Saharan Countries. Int. J. Digital Earth 2008, 1 (3), 247–258.
(8) URT-PM. An Integrated Disaster Management Training Manual (IDMTM) For Tanzania; Disaster Management Department, Prime Minister’s Office: United Republic of Tanzania, 2011.
(9) Becker, P. Scoping Study for Capacity Development in Disaster Management between Tanzania and Sweden; Disaster Management Department, Office of the Prime Minister: Tanzania MSB, Sweden, 2011.
(10) Lubida, A.; Pilesjö, P.; Espling, M.; Runnström, M. Applying the Theory of Planned Behavior to Explain Geospatial Data Sharing for Urban Planning and Management: Cases from Urban Centers in Tanzania. Afr. Geogr. Rev. 2015, 34 (2), 165–181.
