International Journal of Spatial Data Infrastructures Research, 2016, Vol.11, 98-127

Assessment of Spatial Data Infrastructure from a Risk Perspective *

Ali Kalantari Oskouei[1], Mahdi Modiri[2], Aliasghar Alesheikh[3], Reza Hosnavi[2]

[1,2,4]MUT University of Technology, Tehran, Iran, oskhom@gmail.com; mmodiri@ut.ac.ir; hosnavi@mut.ac.ir

[3]K.N.Toosi University of Technology, Tehran, Iran, alesheikh@kntu.ac.ir

Abstract

This research presents an operational framework to assess organizational Spatial Data Infrastructures (SDIs) from a risk perspective to develop a stable SDI. The core of the framework is constructed based on a survey, fuzzy inference system and cluster analysis, providing quantitative indicators to measure and prioritize the risks to SDI. This framework could mainly contribute to identifying, mitigating or avoiding the potential risks of different aspects of an SDI, such as spatial data and information, organizational and technological aspects. Additionally, it could be considered as an approach that supports multi-view SDI assessment framework toward a more comprehensive assessment of SDIs. A prototype implementation to assess and prioritize the risks of the spatial data and information demonstrates the framework merit, flexibility and usability for assessing the risks of SDI initiatives at different levels, such as organizational, local and national levels; however, the risks and SDIs change over time; thus, the development of stable SDI initiatives depends on a continuous process for coping with the risks.

Keywords: Cluster analysis, financial risk, fuzzy inference system, operational risk, organizational SDI

DOI: 10.2902/1725-0463.2016.11.art6

1. INTRODUCTION

Over time, Spatial Data Infrastructures (SDI) assessment activities have increased significantly, resulting in the development of many assessment views to assess SDIs. The most important activities performed in this respect include examining the eleven national initiatives as the first generation of national spatial data infrastructures (Masser, 1999), the survey of the worldwide status of clearinghouses (Crompvoets and Bregt, 2003), the study of the organizational aspects of SDI (Kok and Loenen, 2005), the assessment of the SDI readiness index (Delgado et al., 2005), measuring SDI performance (Giff and Crompvoets, 2008), multi-view assessment framework (Grus et al., 2010) and an online self-assessment methodology for SDIs (Giff and Jackson, 2013). Though the efforts of these authors and the SDI community are commendable, it seems that those efforts ignore assessing SDIs from a risk perspective, which contributes to developing stable infrastructures that operate in normal and abnormal conditions and is also considered to be a very important task of the managerial process of every complex system, such as transportation, communication or information systems. In the case of SDIs, de Man (2008) argues that the assessment of SDIs is non-trivial for a number of reasons. First, the concept is ambiguous, and its understanding requires cross-disciplinary research. Moreover, SDIs are multi-faceted and have a reciprocal (dual) relationship with their (societal) context. Finally, the assessment itself, including that of SDIs, is non-trivial, as the general evaluation and assessment discourse clearly demonstrate that the development of stable SDI initiatives has to cope with risk (de Man, 2008). The literature reviews clearly indicated that there is an information gap regarding the availability of the operational assessment framework to assess risks to SDIs (risk-based study); also, little is known regarding how to incorporate the risk concept into SDI assessment. Therefore, the main objective of this research is to develop and introduce a practical framework to assess the risks of an SDI at the organizational level. It is expected that the proposed risk assessment framework raises SDI resiliency and stability, namely, the ability of SDIs to maintain their functionality and processes after experiencing changes in policies, technology, the environment and so forth. The results could contribute 1) to identifying SDI initiatives' strengths, weaknesses and threats so that by planning for unexpected events, decision makers can be ready to respond if they arise; 2) to ensuring the SDI initiative's success through the process of identifying, mitigating or avoiding potential risks to SDIs; and 3) to broadening the knowledge of the SDI community in the context of SDI risk assessment as a novel methodology to assess SDIs.

Risk is defined as the probability of a particular critical infrastructure's vulnerability being exploited by a particular threat weighted by the impact of that exploitation (Axelrod, 2003). In the context of SDI, the vulnerabilities include not only the damage to the SDI itself but also the harm to all those who rely on the SDI. The SDI risk assessment could be mainly conducted to identify what the risks (possible obstacles) are and then establish a prioritization of these risks to concentrate on the serious concerns. In the risk assessment process, the methodology of calculation of risk and the comparison of risks to determine the priorities play an important role. Two factors, including the probability of occurrence and impact, are introduced as factors affecting the risk. However, the concept of risk is noticeably wide. It can refer to financial, organizational, security, technology and other types of risk; finding a pattern or mathematical relation between the affecting factors and the value (level) of the risk seems to be impossible for researchers (Jasbi and Khanmohammadi, 2009). Thus, based on the literature review, the judgment and knowledge of experts can help to determine the level of risk and to find suitable solutions for risk management. As the literature review shows, there are different methods for analyzing and evaluating experts' judgments in assessing risk. After analyzing the advantages and disadvantages of every method, it seems that no theory is perfect; however, the fuzzy logic model was chosen to assess SDI risks because this model is more objective and suitable for the risk analyses of highly dynamic systems such as SDIs, whereas other approaches are often impractical and cannot be used with the non-accurate inputs obtained from experts' opinions. Therefore, a practical framework based on the fuzzy logic model is proposed in this paper to assess the risks to organizational SDIs.

This paper is organized as follows: the second section provides some basic concepts regarding the experts' judgments evaluation methods, fuzzy logic model and cluster analysis. Section 3 develops an organizational SDI risk assessment framework. Section 4 explains an application of the proposed framework, with an emphasis on spatial data and information possible risks; Section 5 discusses the conclusions and recommendations of the research.

2. BASIC CONCEPTS

This section provides some basic concepts in the context of the different methods of analyzing and evaluating experts' judgments, fuzzy logic principles and cluster analysis theory to support the framework and methodology of the research.

2.1. The Experts' Judgments Evaluation Methods

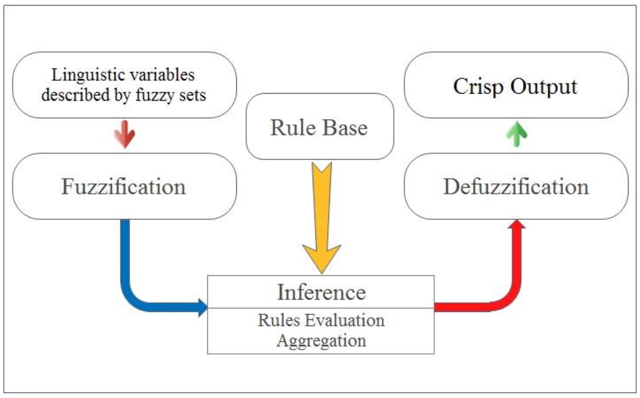
As mentioned earlier, the judgment and knowledge of experts can be used to determine the level of risk based on different methods. A number of those methods include statistical methods (Orabi 2003), the matrix method (KarimiAzari et al., 2011), decision trees (Sherali et al., 2008), artificial neural networks (Angelini et al., 2008), sensitivity analysis (Mokhtari and Christopher, 2005) and fault trees (Abdelgawad and Fayek, 2010), Monte Carlo simulation (Sadeghi et al, 2011) and fuzzy logic models (Dikman et al., 2007).

Statistical methods are fast and easy to use; however, they require numerical data and cannot address imprecise and vague data, which is common in risk assessments. The matrix method is another technique that is simple and adjustable to fit any project. However, it prioritizes the risks based on a very subjective and inaccurate approach. The third technique is the decision tree method, which is flexible and based on the probability and impact of risks; however, its application depends on the availability of historical data. Another technique is Monte Carlo simulation (or probability simulation), which is used to understand the impact of risk and uncertainty in financial, project management, cost, and other forecasting models. Additionally, it can simulate real results based on the probability functions, but it requires a huge amount of data, and most importantly, its estimation of the risks is inaccurate. Another technique is a sensitivity analysis, which provides the possibility to rank risk items based on their significance; however, it suffers from the lack of an indication of the overall risks in the project. The fault tree technique is another method that can identify the root causes of risk items, but it is unable to define the importance of weights for the experts. The artificial neural network is another method that is used to quantify risks. It has been applied to identify the most common risk factors in infrastructure projects and presents a tool to predict the possible cost of risks; nevertheless, it requires historical data. The last technique used to assess risk items is fuzzy logic. The term fuzzy logic was introduced by Zadeh in 1965; it is a form of many-valued logic in which the truth values of variables may be any real number between 0 and 1. It has been applied to many fields, from control theory to artificial intelligence. Fuzzy logic provides a clear methodology to aggregate experts' opinions linguistically and also incorporates experts' qualifications. Moreover, fuzzy logic can calculate using non-accurate and vague data; therefore, the assessment does not rely only on data that can be exactly measured. The fuzzy approach is suitable for assessing highly dynamic systems where there are regular changes in the values of input data (Bok et al, 2012). The main disadvantage of this method is related to the problem of the execution of the arithmetic procedure. Moreover, depending on the conjunction, disjunctions, implications and defuzzification choices, many different fuzzy system configurations may arise in practice.

2.2. Fuzzy Inference System

The fuzzy logic process is defined by a number of names, such as the fuzzy logic model, the fuzzy expert system, the fuzzy rule-based system, the fuzzy system and the Fuzzy Inference System (FIS), in which the crisp input is first converted to a fuzzy set (fuzzification), and then an inference engine, using the knowledge in the form of fuzzy rules contained in a rule-base, computes the output of each rule. These outputs are subsequently aggregated and converted to a crisp number (defuzzification). Figure 1 shows the structure of a fuzzy inference system.

Figure 1: Structure of a Fuzzy Inference System



As figure 1 depicts, a fuzzy inference system addresses linguistic variables. The linguistic variable is a key concept and is defined as a variable whose values are words or sentences in natural or artificial languages. Every linguistic variable can have values in word form, which are called terms or labels of linguistic variables. To illustrate the concept of linguistic variables, we consider the word risk, which cannot be characterized precisely and is described approximately in natural language. Here, the risk is called a linguistic variable, whose values can be words (terms) such as very low, low, moderate, high and very high. The terms of linguistic variables are defined by appropriate membership functions or fuzzy sets, such as triangular, trapezoidal, Gaussian or bell-type shapes. Moreover, the rules play an important role in the fuzzy logic model. A rule composed of two parts, including an antecedent (If part) and a consequent (Then part), is used to define the relationship between the inputs and outputs of fuzzy inference systems. In practice, fuzzy inference systems have dozens of rules, which are combined using fuzzy logic operators, such as AND, OR, and NOT. The number of linguistic variables and the number of terms of each linguistic variable determine the number of possible rules (Zimmermann, H.J., 2010). The construction of the rules is implemented based on the experience and knowledge of human experts and/or the available literature (Ahadi Oroumieh, A., 2015).

The inference is also derived from the evaluation of a set of fuzzy rules (implication) and then the aggregation of the results of rules for given inputs. Typical methods for inference are the Mamdani, Larsen, Tsukamoto, and TSK methods (Lee, 2005). Mamdani is the most used method in many applications for implication and aggregation processes. The Mamdani method uses the minimum (MIN) and MAX-MIN operators for implication and aggregation, respectively. Based on the Mamdani method, the fuzzy implications of the individual rules using the MIN operator are performed, and the MAX-MIN operator then combines the results of the individual rules to produce one membership function as the output.

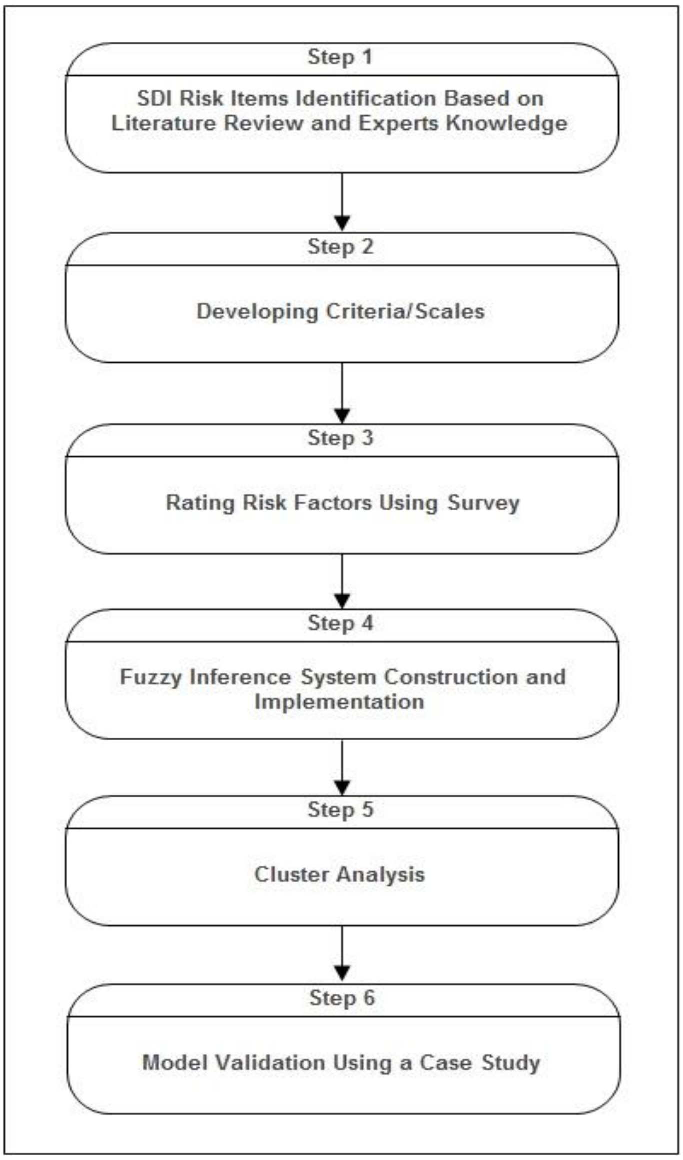
2.3. Cluster Analysis

The results obtained from a fuzzy inference system (the risk scores) need to be classified into groups for better understanding, comparison and management. The cluster analysis is a statistical classification technique in which cases, data (observations), or objects (events, people, things, etc.) are sub-divided into groups (clusters) such that the items in a cluster are very similar (but not identical) to one another and very different from the items in other clusters (Business Dictionary, 2015). There are a number of different methods that can be used to carry out a cluster analysis. These methods can be classified as hierarchical methods or non-hierarchical methods (K-means clustering methods). Hierarchical methods produce a set of nested clusters organized as a hierarchical tree and can be represented on a diagram known as a dendrogram (the root of a tree consists of a single cluster containing all observations, while the leaves correspond to individual observations.). They can be either agglomerative, meaning that groups are merged, or divisive, meaning that one or more groups are split at each stage. Agglomerative methods are used more often than divisive methods. Non-hierarchical methods or K-means clustering aim to partition n observations into k clusters, in which each observation belongs to the cluster with the nearest mean. In these methods, the desired number of clusters is specified in advance, and the best solution is chosen (Tan et al. 2006).

3. SDI RISK ASSESSMENT FRAMEWORK

The development of a framework for assessing the risks to SDI is carried out in six steps, including the following: (1) identifying the key risks impacting SDI, (2) developing assessment criteria and fuzzy linguistic rating scales, (3) rating risk factors using a survey, (4) developing a fuzzy inference system, (5) performing cluster analysis and (6) implementing a case study to validate the model (figure 2). The following sub-sections describe each of these steps in greater detail:

Figure 2: Steps of SDI Risk Assessment Framework



3.1. Identifying Risks to SDI

Before getting into the subject of risk identification, there is a need to clarify the concept of risk in this paper. As the literature review shows, there are many obstacles that influence the development, implementation and maintenance of

SDIs; many studies have tried to develop a methodology to distinguish these obstacles. However, none of them have examined an obstacle of SDI development as a risk event. Different definitions of risk can be found in the literature. Here, a risk is considered to be an obstacle to SDI development and is defined as an event that may possibly occur, and if it did occur, it would have a negative impact on the goals of the SDI and the relevant components (spatial data and information, access network and so on).

As figure 2 depicts, identifying risks is the first and perhaps most critical step in the SDI risk assessment framework because SDI custodians cannot be expected to control the risks they are unaware of. Risk identification is defined as the process of finding, recognizing, and describing risks. The risk identification process precedes risk assessment and produces a comprehensive list of risks, organized by risk category. A comprehensive risk identification of an organizational SDI should mainly cover the possible risks to the spatial data and information, access network, policies, people, organizational, security and financial issues. Although a list of risks will never be exhaustive, it can be the focus of attention in the management of risks.

The techniques that can be used in risk identification are as varied as the projects they serve. However, some most common techniques include literature review, historical data, expert knowledge and risk questionnaire. The literature review and the use of historical data would seem to be easy tasks. However, to the authors' knowledge, no attempt has been made to identify and document the SDI risks. The only applicable resources include the International Standard Organization (ISO) and National Institute of Standards and Technology (NIST) standard documents, e.g., ISO/IEC 27005, ISO/IEC 27002, ISO/IEC 27001 and NIST Information Security publications, which can be proposed as the most important resources. The risk items introduced in these documents were mainly used in the information technology area; however, a noticeable number of them can be applied in the SDI risks identification process. Expert interviews are an especially useful technique in risk identification. A risk questionnaire that includes a series of questions can also be applied effectively to identify risk. The objective is to obtain straightforward, clear narrative statements describing the SDI risks.

To make risks manageable, they must be classified. As the literature review shows, there is no suggestion for classifying risks of SDI. A general method of categorizing risks of SDI could be as operational, financial, organizational, legal, policy, cultural and security categories. It is expected that these categories could cover the SDI components' risks (spatial data, policy, people, standards, and technical aspects) and contribute to achieving rather comprehensive risk categories affecting SDI development.

The operational risks are inherent in all infrastructures, systems, processes, products and activities. The operational risk category refers to an unexpected failure in SDI day-to-day operations. This definition mainly includes human error, failures of information systems, software, hardware and the access network, and problems related to personnel management, fires, floods and a server/service outage. The category of financial risk refers specifically to money issues. The organizational, legal and policy categories cover all unwanted events that arise from the deficiency or lack of coordination, communication, regulation, vision, privacy, access, data sharing and so forth. The security risk category points to events that can stem from intentional failure in SDI operations. In most cases, attention is paid to the events that impact the access network and spatial data and information to protect them from unauthorized use, disruption, modification or destruction (information security). The cost of not paying adequate attention to the security risks can be, for example, the loss of valuable data (spatial and non spatial) or loss of information integrity needed to run an SDI.

It is worth mentioning that once the risks are identified, an assessment of whether a risk is acceptable or it needs to be addressed must be performed. Typically this assessment should consider the severity of the impact of the risks on the SDI components (data, people, access network, standards, policies and financial issues).

As the impacts of the risks on the SDI have not been adequately addressed, the following subjects are presented to give a clear idea of the possible effects. The risks may:

1. Increase the overall cost of the SDI projects in the development, implementation and maintenance phases.
2. Hinder spatial information sharing among organizations.
3. Lead to a loss of integrity, confidentiality and availability of critical spatial and non-spatial information of an SDI.
4. Cause problems of accessing Geo-portals and resources (data and services).
5. Lead to a lack of SDI stability.
6. Impede coordination and cooperation among organizations.
7. Cause time delays in the development of SDIs.

The risks with the high severity of the impacts could destabilize societies. For instance, when the basic infrastructures of a society (such as, telecommunications, energy, transportation, water supply systems, agriculture and emergency services), become highly dependent on the reliable functioning of SDIs, the risks of SDIs could disrupt the orderly functioning of this society.

3.2. Developing Assessment Criteria and Fuzzy Linguistic Rating Scales

A fundamental activity within the risk assessment process is to define a set of assessment criteria. Risk is typically assessed in terms of the probability and severity of the impact factors. Probability indicates the possibility that an event will occur; the impact or consequence indicates the extent to which a risk event might affect the SDI components and its goals.

Most often, the risk, probability and impact factors cannot be identified unequivocally and are considered as vague, imprecise, uncertain, ambiguous and inexact concepts. These factors can be assessed only by using the knowledge of experts. However, due to the difficulty in precisely assessing the risk and relevant factors, experts evaluate them by using a number of linguistic terms or labels. The linguistic terms are words or sentences in a natural or artificial language and are used to rate vague or fuzzy concepts, such as the risk, probability and severity of impact factors. Therefore, here, the rating scales to assess the risk and the relevant factors are constructed based on the linguistic terms.

As the literature review showed, there is no linguistic rating scale available to use in the SDI risk assessment process. Here, this was determined based on the knowledge of competent experts. To create the linguistic rating scales for the risk, probability and severity of impact factors, interviews with eight experts, who had adequate knowledge in the context of SDI, were conducted. The experts recommended one linguistic rating scale composed of five rating points, including very high, high, medium, low and very low (as linguistic terms), to maintain the right balance between simplicity and comprehensiveness. Moreover, the transformation of the linguistic variables to numerical data seems a very difficult task; however, it was accomplished based on the knowledge of experts, resulting in numerical rating scales. The numerical rating scales of probability and impact factors are considered as the input data of the fuzzy inference systems, while the numerical rating scales of the risk factor are used to compare and determine the level of the risk items in the evaluation process. The developed rating scales and their description of the probability, severity of the impact and risk are illustrated in tables 1, 2 and 3, respectively.

Table 1: Probability Factor Assessment Criteria

Linguistic Terms	Rating Scales	Description
Very Low	0 - 0.20	The risk event (obstacle) is negligible and highly unlikely to occur in the process of the development of an SDI.
Low	0.21 - 0.33	The risk event (obstacle) is unlikely to occur in the process of the development of an SDI.

Medium	0.34 - 0.50	The risk event (obstacle) is somewhat likely to occur in the process of the development of an SDI.
High	0.51 - 0.66	The risk event (obstacle) is highly likely to occur in the process of the development of an SDI.
Very High	0.67 - 1	The risk event (obstacle) is almost certain to occur in the process of the development of an SDI.

Table 2: Impact Factor Assessment Criteria

Linguistic Terms	Rating Scales	Description
Very Low	0 - 0.20	The risk event (obstacle) could be expected to have a negligible adverse effect on SDI components and its objectives (data, people, access network, standards, policies, financial issues and so on) in the process of the development of an SDI.
Low	0.21 - 0.33	The risk event (obstacle) could be expected to have a limited adverse effect on SDI components and its objectives (data, people, access network, standards, policies, financial issues and so on) in the process of the development of an SDI. Here, a limited adverse effect means that the obstacle might, for instance, result in a minor effect on SDI components or a minor financial loss. In general, these obstacles are of less importance in SDI development.
Medium	0.34 - 0.50	The risk event (obstacle) could be expected to have a relatively noticeable adverse effect on SDI components and its objectives (data, people, access network, standards, policies, financial issues and so on) in the process of the development of an SDI. Here, a relatively noticeable adverse effect refers to the obstacles that, for example, might result in a relatively negative effect on SDI assets and objectives. These obstacles could reduce the progress of SDI development.
High	0.51 - 0.66	The risk event (obstacle) could be expected to have a serious adverse effect on SDI components and its objectives (data, people, access network, standards, policies, financial issues and so on) in the process of the development of an SDI. A serious adverse effect means that the obstacles might, for example, result in major financial loss or cause a significant degradation in the progress of SDI development. These obstacles may impede the development, implementation and maintenance of an SDI.
Very High	0.67 - 1	The risk event (obstacle) could be expected to have a severe adverse effect on SDI components and its objectives (data, people, access network, standards, policies, financial issues and so on) in the process of the development of an SDI. A severe adverse effect means that, for example, the obstacles

		could result in a serious effect on one or more components and impede the development, implementation and maintenance of an SDI.

Table 3: Risk Assessment Criteria

Linguistic Terms	Rating Scales	Description
Very Low	0 - 0.20	Very low risk means that an obstacle could be expected to have a negligible adverse effect on SDI components and its objectives in the development, implementation and maintenance of an SDI.
Low	0.21 - 0.33	Low risk means that an obstacle could be expected to have a limited adverse effect on SDI components and its objectives in the development, implementation and maintenance of an SDI.
Medium	0.34 - 0.50	Medium risk means that an obstacle could be expected to have a relatively noticeable adverse effect on SDI components and its objectives in the development, implementation and maintenance of an SDI.
High	0.51 - 0.66	High risk means that an obstacle could be expected to have a serious adverse effect on SDI components and its objectives in the development, implementation and maintenance of an SDI.
Very High	0.67 - 1	Very high risk means that an obstacle could be expected to have a severe adverse effect on SDI components and its objectives in the development, implementation and maintenance of an SDI.

Table 1 provides a guideline to help experts rate the probability factor. This scale includes a combination of a 5-level linguistic scale and a 1-point numerical scale (1 being the greatest probability).

A guideline to assess the impact factor (consequence) has been introduced in table 2. As this table shows, the impact of the events is rated though a combination of a 5-level linguistic scale and a 1-point numerical scale (1 being the greatest consequence). The consequences here are mainly expressed with respect to the SDI components and its objectives and assessed based on the available evidence, experience, and expert judgment.

Table 3 provides a guideline to determine the level of risk events as a combination of probability and impact factors. The level of risk events ranges from very low to very high and contributes to evaluating and prioritizing the risk events that affect SDI components and the relevant objectives.

In general, the dynamic nature of the whole SDI concept requires that the probability, impact and risk criteria be continually reviewed.

3.3. Rating Risk Factors Using a Survey

To rate the risk factors, a questionnaire was designed and delivered to the SDI experts of the organizations. The questionnaire comprises two sections. The first section focuses on the demographic information of the experts, such as affiliation, years of experience, academic degree and the role in the organization, which are used to determine the experts' importance weight. The second section of the questionnaire measures the probability and the impact factors for each identified risk item. These questionnaires include a combination of closed questions with a 5-level linguistic scale, including "very low", "low", "moderate", "high" and "very high", to rate SDI risk items.

In most cases, the experts participating in the survey process consist of different experts of the Geomatics community, with a variety of experience, knowledge and expertise. These inequalities are conquered by assigning an importance weight factor for each expert, derived from the survey, based on the following equation:

$$C_1 + C_2 + \dots C_n = 1 \quad (1)$$

where C refers to a normalized weight factor of each expert (ranges from 0 to 1). The weight values are multiplied by risk factors in the process of risk calculation.

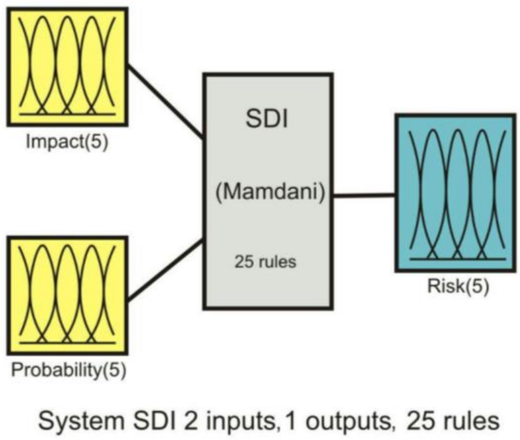
3.4. Developing a Fuzzy Inference System for Assessing Risks to SDI

There are, essentially, four fundamental stages in the construction of a fuzzy inference system to assess SDI risks.

3.4.1. Determination of Input and Output Variables, Fuzzification and Membership Functions

This stage defines what data flows into the system and what information is eventually output from the system. An SDI risk assessment fuzzy inference system is built, with the probability and impact factors as two input variables and a risk factor as the output variable (figure 3).

Figure 3: Structure of the Fuzzy Inference System for SDI Risk Assessment



Fuzzification of the inputs and output variables is carried out by dividing them into five different fuzzy linguistic sets (terms): Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH). In what follows, each of these terms is modeled by a Gaussian membership function, as presented in figures 4, 5, and 6. The Gaussian function is considered as a fuzzification function; it is selected because it is tractable, smooth, nonzero at all points, a reliable performer and used in many risk assessment applications (Ahadi, 2015).

Figure 4: The Probability Variable Membership Function

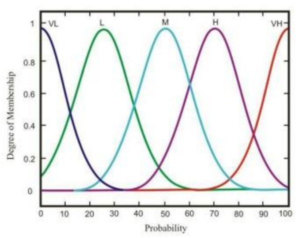


Figure 5: The Impact Variable Membership Function

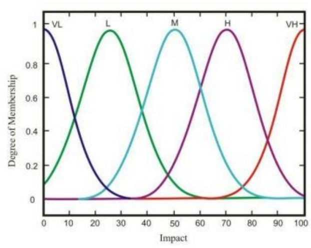
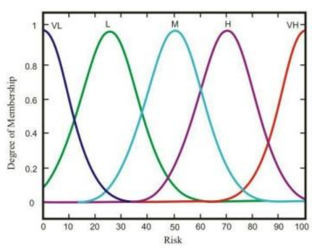


Figure 6: The Risk Variable Membership Function



3.4.2. Construction of Rules Base

The rules describe how the system operates. In relation to rules for SDI risk assessment, no attempt so far has been made; however, an SDI risk fuzzy inference system is built using 25 fuzzy rules. In this process, the input variables and corresponding linguistic terms are written in the antecedent part, while the output variable and corresponding linguistic terms are used in the consequent part of each rule. Rules are constructed based on experts' knowledge and available literatures. A number of developed rules for use in the SDI risk fuzzy inference system are presented in table 4.

Table 4: Some Developed If … Then Rules

Rule 1: If (Impact is VL) and (Probability is VL), then Risk is VL
Rule 2: If (Impact is L) and (Probability is L), then Risk is L
Rule 3: If (Impact is L) and (Probability is H), then Risk is L
Rule 4: If (Impact is VH) and (Probability is M), then Risk is H
Rule 5: If (Impact is L) and (Probability is H), then Risk is L

3.4.3. Determination of Inference Method

In general, the inference is determined based on two factors: the implication operator and the composition operator. The SDI risk fuzzy inference system benefits from the Mamdani implication MIN and the Mamdani aggregation MAX-MIN operators for implication and aggregation, respectively.

3.4.4. Determination of Defuzzification Method

The defuzzification procedure for the SDI risk fuzzy inference system is achieved via the center of area method, which returns the center of the area under the curve and is the commonly used method for defuzzification in risk assessment.

The input to the defuzzification process is a fuzzy set (the aggregate output fuzzy set), and the output is a single number. This number is considered as a risk index, a quantity that provides information regarding the risk level, for each risk item. The overall risk index value can also be achieved using geometric mean, which presents our knowledge and belief regarding a specific aspect of the risk of a future system operation such as SDI.

3.5. Cluster Analysis

Having determined the SDI risk item indices, a cluster analysis can be used to divide SDI risks, based on the corresponding risk index, into groups (clusters) such that the risks in a cluster are very similar (but not identical) to one another and very different from the risks in other clusters. As in utilizing the hierarchical methods, there is no need that the number of clusters be specified in advance; therefore, the hierarchical agglomerative procedure is applied as a clustering technique to group SDI risk items.

3.6. Model Validation Using a Case Study

3.6.1. Study Area

Iran, a country located in the Middle East, was the study area of the research. Iran consists of 31 provinces and 18 ministries. Concerning SDI development, the Iranian National Cartographic Center (NCC) is in charge of developing SDI in the country. Currently, the ministries attempt to take advantage of the SDI at the national and organizational levels.

3.6.2. Case Study

A case study was conducted to validate and illustrate the application of the proposed methodology. Due to the large number and the diversity of possible risks of an SDI and its components, this case study was limited to assessing the possible risks that affect spatial data and information of an SDI at the organizational level. To do so, six of Iran's public organizations, with experience in GIS and SDI activities, were chosen to be studied in this case study (table 5). First, in the risk identification step, 160 risk items were identified based on the opinion of the eight experienced Geomatics industry experts, ISO (ISO 2005, 2011) and NIST (NIST, 2012) documents. However, only 32 risk items that were mainly associated with spatial data and information were selected for further processes. The list of selected risk items and relevant categories is shown in table 6. In what follows, the selected public organizations, i.e., water organization, municipality, national cartography center, industry, mine and trading organization, agricultural organization and Gas Company, were visited to conduct a questionnaire-based survey and receive the opinion of competent experts (the respondents) during 2015 (table 5). Due to the scarcity of competent SDI/GIS experts in the organizations, the number of respondents was limited to 18 experts. Additionally, there was a limitation in finding organizations involved in SDI-related activities. This limitation confined the scope of the research to six organizations.

The respondents were asked about the probability of occurrence and the degree of loss (severity of impact), measured on a five-point linguistic scale (from very low to very high), for each risk item. After completing the survey, a fuzzy inference system was constructed using the risk, the probability of occurrence, the degree of loss (severity of impact) variables, the 25 "If ... Then" rules and the Mamdani inference method. The scores of risk items were calculated using the developed inference system within the MatlabR software and then all were evaluated on the basis of the risk assessment criteria of table 3. The results are shown in table 6.

Table 5: Information Regarding Organizations and Respondents

Organizations	Number of respondents	Academic degree	Geomatics experience (Year)	Role in the organization
Water organization	3	MSc	15,10,12	GIS manager & expert
Municipality	3	MSc	15,10,9	SDI & GIS manager & expert
National Cartography Centre	4	PhD & MSc	20, 14,15,15	SDI & GIS manager & expert
Industry, mine and trading office	2	MSc & B.S.	10,11	GIS manager & expert
Agriculture organization	4	PhD, MSc, B.S.	12,20,18,10	GIS manager & expert
Gas Company	2	MSc	15,10	GIS manager & expert
Total	18			

Table 6: The 32 Selected Risk Items, Categories, Risk Scores and Risk Levels

Risk no.	Risk category	Risk description	Risk scores	Risk level
1	Operational	Lack of metadata creation process	0.70	Very High
2	Operational	Lack of a mechanism to update spatial data and metadata	0.69	Very High
3	Operational	Inadequate or irregular metadata creation	0.71	Very High
4	Financial	Inadequacy of the budget of SDI projects	0.69	Very High
5	Operational	Lack of a mechanism to control the proper functioning of the backups /archives.	0.69	Very High
6	Operational	Improper maintenance (environmental conditions) of spatial data and information of SDI	0.69	Very High
7	Operational	Lack of backup/archive of spatial data and information	0.62	High
8	Organizational	Lack of inter-agency cooperation and coordination for data sharing	0.62	High
9	Financial	Increased costs due to incomplete or wrong hardware / software selection	0.65	High
10	Organizational	Lack of support for SDI on behalf of top-level managers	0.57	High
11	Operational	Employing temporary technical personnel in relation to SDI project	0.66	High
12	Security	Lack of training courses in relation to spatial	0.61	High

		data and information security		
13	Operational	Lack of scheduling and forecasting regarding how to use SDI in emergency situations (disasters)	0.61	High
14	Operational	Problem of retrieving spatial data in the shortest time in an emergency situation	0.66	High
15	Operational	Employing irrelevant experts in SDI project	0.56	High
16	Operational	The lack of spatial data and metadata standards in SDI project	0.62	High
17	Security	Lack of a mechanism to protect spatial data and information against virus, Trojan.	0.62	High
18	Operational	Inadequate or irregular backup/archive making for spatial data and information	0.55	High
19	Operational	Lack of backup server/s	0.63	High
20	Security	Disclosure of important spatial data and information of SDI	0.59	High
21	Security	Lack of password for important spatial data and information of SDI	0.64	High
22	Security	Lack of responsible person for security of spatial data and information of SDI	0.65	High
23	Security	Establishment of main servers and backup servers in a single place	0.58	High
24	Security	Unauthorized copying and reproduction of spatial data and information of SDI	0.53	High
25	Operational	Damage to spatial data and information due to a power outage/oscillation	0.40	Medium
26	Operational	Lack of access to spatial information due to lack of required hardware	0.47	Medium
27	Operational	Manipulation or falsification of SDI databases and metadata	0.41	Medium
28	Security	Incorrect classification of spatial data and information	0.47	Medium
29	Operational	Lack of native spatial data and metadata management applications	0.39	Medium
30	Security	Damage to spatial data and information from disgruntled employees	0.33	Low
31	Security	Damage to spatial data and information from external parties	0.28	Low
32	Security	Password theft	0.29	Low
Overall Geometric Mean			0.5520	

Based on the results, the most important critical risk items to organizational SDIs were the lack of metadata creation, lack of a mechanism to update spatial data and metadata, lack of a mechanism to control the proper functioning of the backups/archives and inadequacy of the budget of SDI projects, lack of backup/archive of spatial data and information, lack of inter-agency cooperation and coordination for the SDI project and the lack of support for SDI on behalf of top-level managers. It should be noted that the status of metadata creation and updating issues were not the same for all of the organizations. For instance, the National Cartography Center has created many ready to use metadata records, while other organizations suffer from the lack of minimum required metadata. Regarding the budget of SDI projects, all of the organizations depend on the central government, and it seems that there is not an appropriate financial support for development of SDI on behalf of the central government. Moreover, the issue of the backup/archive of spatial data and information was identified as a common problem for entire organizations. Though it is a vital problem in crisis conditions, it seems, however, that the organizations have no solution to overcome this problem. Regarding inter-agency cooperation and coordination to share spatial data and information, it seems that the lack of a policy for data sharing (access, restriction and pricing) and the lack of partnership between data producers and legal issues, such as copyright, liability and privacy, may restrict the process of spatial data sharing. Additionally, in most of the organizations, the view of the top-level managers concerning SDI initiatives was identified at a low level of awareness in relation to SDI benefits and the roles that SDI could play in the organization missions.

Moreover, the statistical analysis showed that risk level of 18.75% of risk items was identified as very high, 56.25% as high, 16% as medium and 9% as low (table 7). Moreover, the overall geometric mean value of the 32 risk items (risk index) for organizational SDIs was calculated as 0.5520 or 55.20% (figure 7). Based on the criteria provided in table 3, this overall index shows that the impact of the risk items on SDI is at a relatively high level, and the implementation of the SDI initiatives in most organizations requires coping with many risk items. The overall risk index ranges from 0 to 100%, where 0 indicates a risk-free environment (without obstacles), and 100 denotes a very high risk environment (maximum obstacles).

Figure 7: Overall SDI Risk Index

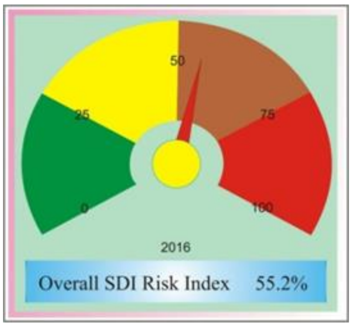


Table 7: The Statistical Results of 32 Risk Items in Terms of Level of Risk

	Risk level of 32 risk items	Number of risk items	Percent	Geometric mean (%) of risk item indices
	Very High	6	18.75	69.31
	High	18	56.25	60.83
	Medium	5	16	42.73
	Low	3	9	29.95
	Total	32	100	

Analyzing the results in terms of the four types of risk revealed that the financial, operational, organizational and security risk categories obtained a 67, 59, 59 and 47% overall risk index, respectively (figures 8, 9, 10 and 11). With regard to this result, it seems that the operational, organizational and financial issues play a more important role than the security issues in the development of an organizational SDI.

Figure 8: Overall Risk Index of the Financial Risk Items

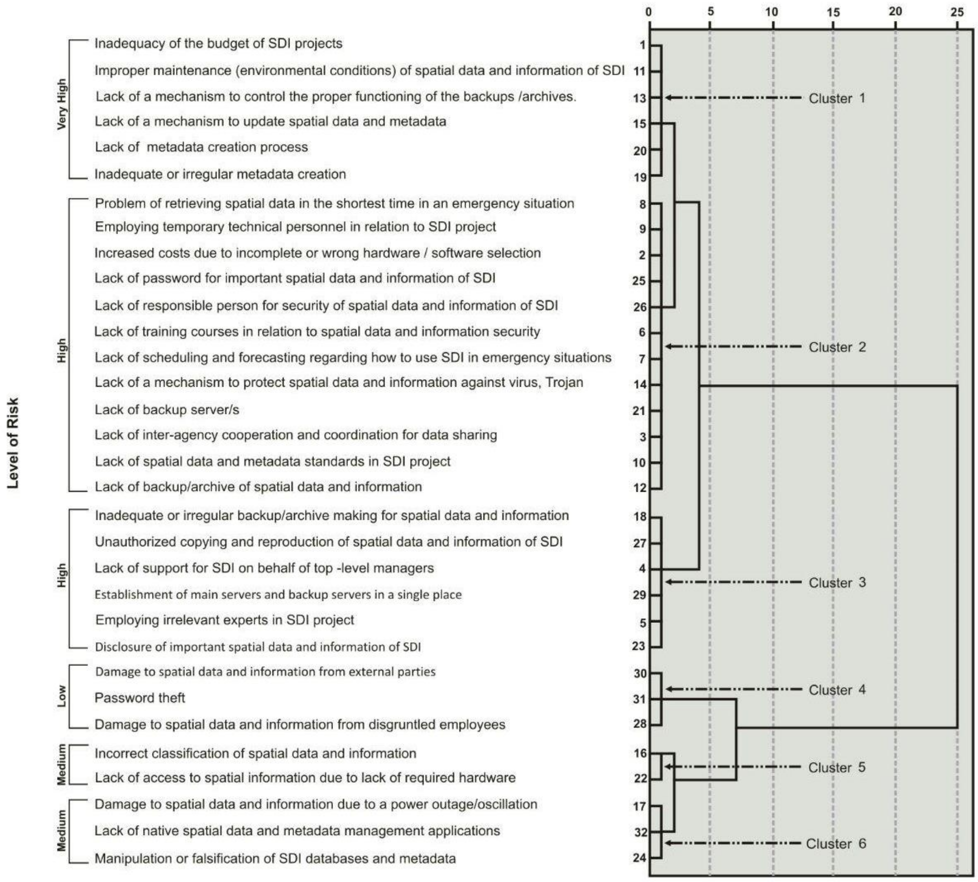
Figure 9: Overall Risk Index of the Operational Risk Items

Figure 10: Overall Risk Index of the Organizational Risk Items

Figure 11: Overall Risk Index of the Security Risk Items

Moreover, by applying a hierarchical cluster analysis, based on the risk item indices, we categorized the 32 SDI risk items into six homogenous groups (clusters). The dendrogram for this analysis is shown in figure 12.

Figure 12: The Dendrogram of Cluster Analysis for the 32 Risk Items



As figure 12 shows, each cluster contained different numbers of risk items, which are explained in the following:

8. The SDI risk items of the first cluster: the SDI risk items with the highest risk level, including the inadequate or irregular metadata creation, lack of metadata creation process, lack of a mechanism to update spatial data and metadata, lack of a mechanism to control the proper functioning of the backups /archives, inadequacy of the budget of SDI projects and improper maintenance (environmental conditions) of spatial data and information of SDI, were classified in this cluster. This cluster contained 18.75% of the total

risk items, and its geometric mean value was higher than the mean of all clusters and the overall risk mean value.

9. The SDI risk items of the second cluster: the largest number of SDI risk items was classified in this cluster (37.5%). Risk items of this cluster include: problem of retrieving spatial data in the shortest time in an emergency situation, employing temporary technical personnel in relation to SDI project, increased costs due to incomplete or wrong hardware / software selection, lack of responsible person for security of spatial data and information of SDI, lack of password for important spatial data and information of SDI, lack of backup server/s, lack of a mechanism to protect spatial data and information against virus, Trojan, lack of backup/archive of spatial data and information, lack of spatial data and metadata standards in SDI project, lack of inter-agency cooperation and coordination for data sharing, lack of training courses in relation to spatial data and information security, and lack of scheduling and forecasting regarding how to use SDI in emergency situations. The geometric mean value of this cluster was less than the cluster 1 mean value and higher than the overall risk mean value.
10. The SDI risk items of the third cluster: 18.75% of the SDI risk items belonged to this cluster. The cluster risk items include: establishment of main servers and backup servers in a single place, lack of support for SDI on behalf of top - level managers, employing irrelevant experts in SDI project, inadequate or irregular backup/archive making for spatial data and information, unauthorized copying and reproduction of spatial data and information of SDI and disclosure of important spatial data and information of SDI. The geometric mean value of the risk items of this cluster was less than the cluster 1 and cluster 2 mean values but relatively close to the overall risk mean value.
11. The SDI risk items of the fourth cluster: this cluster contained three risk items (9.375%) including damage to spatial data and information from external parties, password theft and damage to spatial data and information from disgruntled employees. The geometric mean value of this cluster was the lowest compared to other clusters.
12. The SDI risk items of the fifth cluster: the lowest number of SDI risk items was classified in this cluster (6.25%). Risk items of this cluster include: incorrect classification of spatial data and information and lack of access to spatial information due to lack of required hardware. The geometric mean value of this cluster was less than the overall risk mean value and higher than the clusters 3 and 6 mean values.
13. The SDI risk items of the sixth cluster: manipulation or falsification of SDI databases and metadata, damage to spatial data and information due to a power outage/oscillation and lack of native spatial data and metadata management applications risk items were classified in the fifth cluster. The geometric mean value of this cluster was less than the overall risk mean value and higher than the cluster 4 mean value.

Taking a closer look at the results provided in table 6 and the results of cluster analysis revealed that SDI risk items with a very high risk level were classified in cluster 1; high level items in cluster 2 and 3; low level items in cluster 4 and medium level items in clusters 5 and 6 (figure 12). Table 8 shows the statistical analysis results of the cluster analysis. The level of risk of clusters shown in table 8 was determined on the basis of the criteria introduced in table 3. Based on this table, the priority ranking of the six SDI risk clusters can be identified as:

Cluster 1>Cluster 2>Cluster 3>Cluster 5>Cluster 6>Cluster 4

This ranking plays an effective role in situations where there is not enough time and/or resources to cope with all risk items.

Table 8: The Statistical Results of the Cluster Analysis

Cluster number	Number of risk items	Percent	Geometric mean (%) of risk item indices	Level of risk
1	6	18.75	69.35	Very High
2	12	37.5	63.10	High
3	6	18.75	56.52	High
4	3	9.375	29.95	Low
5	2	6.25	47.21	Medium
6	3	9.375	39.98	Medium
Total	32	100		

As table 8 shows the level of risk of clusters 2 and 3 as well as clusters 5 and 6 were similar. So, the number of clusters, in terms of the level of risk, can be reduced to 4 clusters.

In sum, it could be concluded that in the absence of specific criteria of risk assessment, such as the criteria provided in table 3, the cluster analysis as a primary and effective tool can contribute to grouping the criticality of risk items in the SDI risk assessment process. To do so, it is required that the geometric mean of the clusters to be compared and prioritized with the expert's knowledge.

3.6.3. Model Validation

To evaluate the validity of the model, a survey was conducted by eight competent experts, having 15 to 20 years experience in the SDI, Geomatics and GIS fields, to rank the different risk items according to their criticality to organizational SDI initiatives development. The survey questionnaire contained questions with the five-point linguistic rating scales (Very High, High, Medium, Low and Very Low) to determine the criticality of the 32 risk items. In what follows, the results of the survey (a real rating) were compared to the model results, and the mean percentage of the error for each risk item was then determined using equation (2), where k refers to the number of experts, and the model and the real ratings are results of the fuzzy model and the expert-based survey, respectively.

$$Mean\ error\ (\%) = \frac{\left|\sum_1^k \frac{Model\ Rating_i - Real\ Rating_i}{Real\ rating_i}\right|}{k} \times 100 \qquad (2)$$

Based on equation 2, the overall mean percentage error was calculated as 8.85%. This value is relatively low and could imply the merit of the model to assess the SDI risk items. The most important risk items that were different in the model, and the survey results included the damage to spatial data and information from disgruntled employees, the lack of access to spatial information due to a lack of required hardware, the disclosure of important spatial data and information of SDI, the password theft and damage to spatial data, and information from external parties. With regard to this result, it seems that the lack of complete agreement between the model and survey results might be associated with the different conditions of the organizations and also the different levels of knowledge and experience of the experts that participated in the research.

4. CONCLUSIONS

SDIs need to strengthen their stability to ensure continued operation and survival in the face of risks. Therefore, the main objective of this research was to develop an operational framework for assessing organizational SDIs from a risk perspective, which makes it possible to develop a stable SDI. The proposed SDI risk assessment framework can be used to assess and prioritize the possible risks (obstacles) that may have a negative impact on the different components of SDI, including spatial data and information, technology (network, software, hardware, and processes), organizational/legal issues, policies, people and standards. Due to the wide diversity of the risks affecting the SDI components and its objectives, the focus of this research was limited to assessing the risks of spatial data and information component, which is known as the central pillar of the SDIs. This research does not attempt to provide a comprehensive list of the risks to SDI and its components. The list of risks provided in this research was designed to help implement and demonstrate the application of the proposed framework of SDI risk assessment in the real world.

The model validation was conducted using a survey, and it was found that the overall mean percentage error of the model was at a low level. Moreover, the framework was flexible because it is built on a fuzzy inference system that permits different risk items and logic rules to be added, removed or corrected without the need to modify the whole system. This flexibility allows the framework to be applied to SDIs at different levels, such as local and national levels. However, the dynamic nature of the SDIs requires coping with the risks in a continuous process. Therefore, it seems that the risk studies should be a continuous and regular activity in the organizations implementing SDI to keep SDIs robust and stable over time and during normal and crisis conditions.

The results from the case study indicated that in the organizational SDIs, operational, organizational and financial risks are more important than security risks, and the major risk items that could prohibit the success of an SDI are the lack of creation and updating of the documentation of data (metadata) and spatial data, the inadequacy of the budget of SDI projects, the lack of a backup/archive of spatial data and information, the lack of a mechanism to control the proper functioning of the backups/archives, the lack of inter-agency cooperation and coordination in an SDI project for data sharing, and the lack of support for SDI on behalf of top-level managers. Moreover, the scarcity of competent SDI experts and the inadequate number of organizations involved in SDI-related activities were identified as the main limitations that can influence the results of the study.

Generally, it is expected that the experience of the proposed framework could contribute to supporting multi-view SDI assessment framework. The multi-view SDI assessment framework has been introduced for assessing SDI initiatives around the world; the strength of this assessment design lies in its flexibility, the multidisciplinary view of SDI and a reduced bias in the assessment results. This framework contains methods that not only evaluate SDI performance but also deepen our knowledge regarding SDI functioning and may assist in its development (Grus et al. 2008). However, as Grus (2010) argues, the relatively small number of operational SDI assessment views and their approaches limits the potential of the multi-view SDI assessment framework for a comprehensive SDI assessment; thus, the proposed framework in this paper could be considered as a novel view towards completing the multi-view SDI assessment framework views, approaches and methods.

Finally, to the best of the authors' knowledge, in the future, new technologies, policies, organizational structures, legal issues, standards and other types of changes are needed to achieve SDIs' goals, but with these changes come new risks imposing instability on SDI initiatives, which need to be managed so that what has been presented in this research can be considered as a solution to cope with the possible challenges of the future generations of SDI.

5. RECOMMENDATIONS

1- This research has only carried out a case study of SDI at an organizational level; the research needs to be expanded to include other SDIs at different levels. In this context, an important project would be a risk assessment of the national spatial data infrastructure (NSDI).

2- Exhaustive assessment is not feasible in this research due to the limitations of time and resources. The present research does not consider comprehensively all the risk items and organizations; there are many specific risks and their interactions that have not been addressed and require further research.

3- Developing standards of probability, impact, risk assessment criteria and also a knowledge base (logical rules) to utilize in SDI assessment is recommended for the SDI community and international organizations such as the Global Spatial Data Infrastructure (GSDI) as future work.

4- In this research, the processes of data collection were conducted through a simple survey with a number of experts. It is recommended that the simple survey be replaced by a Delphi technique.

5- The focus of this paper was on the risks affecting the spatial data and information. Further research is of crucial importance for the assessment of the risks that are mainly pertinent to access network, legal, policies, financial and organizational cooperation issues of SDI at different levels.

6. REFERENCES

Abdelgawad, M. and A. Fayek (2010). Risk Management in the Construction Industry Using Combined Fuzzy FMEA and Fuzzy AHP, Journal of Construction Engineering and Management 136(9): 1028-1036.

Amir Ahadi Oroumieh, A. (2015). Supply Chain Risk Assessment of the Iranian Mining Industry by Using Fuzzy Inference System, Uncertain Supply Chain Management Journal, 3(3): 273-282. DOI: 10.5267/j.uscm.2015.3.003.

Angelini, E., T. Giacomo, and A. Roli (2008). A Neural Network Approach for Credit Risk Evaluation, Journal of Quarterly Review of Economics and Finance, 48(4): 733-755. DOI: 10.1016/j.qref.2007.04.001.

Axelrod R. (2003). Risk in Networked Information Systems, Gerald R. Ford School of Public Policy, University of Michigan, at http://www-personal.umich.edu/~axe/risk.pdf , [accessed 12 May 2015].

Boc, K., J. Vaculík, , and D. Vidriková (2012). "Fuzzy Approach to Risk Analysis and its Advantages Against the Qualitative Approach", Proceedings of the 12th International Conference Reliability and Statistics in Transportation and Communication (RelStat'12), October 17-20, Riga, Latvia, pp. 234-239.

Bojadziev, G., and M. Bojadziev (2007). Fuzzy Logic for Business, Finance, and Management: World Scientific Publishing Co. Pte. Ltd.

Business dictionary (2015). At http://www.ciao.gov/CIAO_Document_Library/glossary/R.htm, [accessed 21 July 2015).

Crompvoets, J. and A.K. Bregt (2003). World Status of National Spatial Data Clearinghouses, URISA Journal, Special Issue on Public Participation GIS, 15 (2): 43-50.

Crompvoets, J., A. Rajabifard and I. Williamson (2004). Assessing the Worldwide Developments of National Spatial Data Clearinghouses, International Journal of Geoinformation Science, 18 (7): 665-669.

De Man, E. (2008). "The Multi-Faceted Nature of SDIs and their Assessment - Dealing with Dilemmas", in Crompvoets, J. and A. Rajabifard (Ed.) A Multi-View Framework to Assess Spatial Data Infrastructures, Space for Geoinformation, Wageningen University and Centre for SDIs and Land Administration University of Melbourne, pp. 23-49.

Delgado, F., K. Lance, M. Buck, and H. J. Onsrud (2005). "Assessing an SDI Readiness Index", FIG Working Week and GSDI-8, April 16-21 2005, Cairo, Egypt.

Dikmen, I., M. T. Birgonul, and S. Han (2007). Using Fuzzy Risk Assessment to Rate Cost Overrun Risk In International Construction Projects, International Journal of Project Management, 25(5):494-505. DOI: 10.1016/j.ijproman.2006.12.002.

Giff, G. A. and J. Crompvoets (2008). Performance Indicators a Tool to Support Spatial Data Infrastructure Assessment, Journal of Computers, Environment and Urban Systems, 32(5):365-376. DOI: 10.1016/j.compenvurbsys.2008.08.001.

Giff, G. and J. Jackson (2013). "Towards an Online Self-Assessment Methodology for SDIs", in Onsrud, H. and A. Rajabifard (Ed.) A Spatial Enablement in Support of Economic Development and Poverty Reduction: GSDI Association Press, pp. 99-130.

Grus, L. (2010). Assessing Spatial Data Infrastructure, PhD Dissertation, Wageningen University, The Netherlands.

Grus, L., J. Crompvoets and A.K. Bregt (2008). "Theoretical Introduction to the Multi-View Framework to Assess SDIs", in Crompvoets, J. and A. Rajabifard (Ed.) A Multi-View Framework to Assess Spatial Data Infrastructures, Space for Geoinformation, Wageningen University and Centre for SDIs and Land Administration University of Melbourne, pp. 93-113.

ISO/IEC (2005). Information Technology, Security Techniques, Code of Practice for Information Security Management (ISO/IEC 27002), Second Edition.

ISO/IEC (2005). Information technology, Security Techniques, Information Security Management Systems, Requirements (ISO/IEC 27001), First Edition, Switzerland.

ISO/IEC (2011). Information Technology, Security Techniques, Information Security Risk Management (ISO/IEC 27005), Second Edition, Switzerland.

Jassbi, J., and S. Khanmohammadi (2009). "Organizational Risk Assessment Using Adaptive Neuro-Fuzzy Inference System", Proceedings of the Joint 2009 International Fuzzy Systems Association World Congress and 2009 European Society of Fuzzy Logic and Technology Conference, July 20-24 2009, Lisbon, Portugal, pp. 1217-1222.

KarimiAzari, A., N. Mousavi, S. F Mousavi and S. B. Hosseini (2011). Risk Assessment Model Selection in Construction Industry, International Journal of Expert Systems with Application, 38(2011): 9105-9111.

Kok, B. and B. van Loenen (2005). How to Assess the Success of National Spatial Data Infrastructures?, Computers, Environment and Urban Systems, 29(2005):699-717.

Lee, K. (2005). First Course on Fuzzy Theory and Applications, Berlin: Springer-Verlag.

Masser, I. (1999). All Shapes and Sizes: The First Generation of National Spatial Data Infrastructures, International Journal of Geographical Information Science, 13 (1):67- 84.

Mokhtari, A. and F. H. Christopher (2005). Sensitivity Analysis of a Two-Dimensional Probabilistic Risk Assessment Model Using Analysis of Variance, Journal of Risk Analysis, 25(6): 1511-1529. DOI: 10.1111/j.1539-6924.2005.00679.x.

National Institute of Standards and Technology (NIST) (2012). Information Security, NIST Special Publication 800-30 Revision 1, Gaithersburg, MD 20899-8930.

Orabi, W. M. (2003). Risk Identification and Response Methods in the Egyptian Construction Industry: Views of Large Scale Contractors, Master of Science Thesis, the American University in Cairo, Egypt.

Sadeghi, N., A. R. Fayek, and W. Pedrycz, (2010). Fuzzy Monte Carlo Simulation and Risk Assessment in Construction, Journal of Computer-Aided Civil and Infrastructure Engineering, 2(4): 238-252. DOI: 10.1111/j.1467-8667.2009.00632.x.

Sherali, H. D., J. Desai, and T. S. Glickman (2008). Optimal Allocation of Risk-Reduction Resources in Event Trees, Journal of Management Science, 54(7): 1313-1321.

Stoneburner, G., A. Goguen, and A. Feringa, (2002). Risk Management Guide for Information Technology Systems, Special Publication 800-30, National Institute of Standards and Technology (NIST), at csrc.nist.gov/publications/nistpubs/800-30/sp800-30.pdf, [accessed 3 December 2015].

Tan, P.N., M. Steinbach and V. Kumar (2006). Cluster Analysis: Basic Concepts and Algorithms, at http://www-users.cs.umn.edu/~kumar/dmbook/index.php, [accessed 12 August 2015].

Zimmermann, H. (2010). Fuzzy set theory, Advanced Review, John Wiley & Sons Inc., at www.mv.helsinki.fi/home/niskanen/zimmermann_review.pdf, [accessed 12, August 2015].