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# Geospatial Reasoning Ability of Business Decision Makers: Construct Definition and Measurement

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# Geospatial Reasoning Ability of Business Decision Makers: Construct Definition and Measurement

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## ABSTRACT

Today's organizations often gather large quantities of geographic and geo-spatially referenced data to support business decision-making. While there has been research into the significance of user characteristics on decision-performance when working with geospatial data, there is conflicting knowledge on the necessity of the geospatial reasoning ability of the decision-makers to ensure that efficient and effective decisions are made. As the amount of geographic and geospatially-referenced data expands, it is essential to develop a comprehensive understanding of how user characteristics, such as geospatial reasoning ability, influence decision performance. Furthermore, such an understanding is essential to the growth of knowledge within the human-computer interaction domain. This research introduces a new construct, Geospatial Reasoning Ability of Business Decision Makers, and presents a validated measurement scale to measure this construct.

### Keywords

Decision performance, human-computer interaction, geospatial reasoning ability, cognitive fit theory.

## INTRODUCTION

As geospatial data permeates business computing, researchers and computing professionals have come to realize that there is a vague understanding of the utilization of geographic information to make strategic business decisions, as well as the best ways to utilize geographic data in making such decisions. Scholars have stated that over 75 percent of all business data contains geographic information (Tonkin, 1994) and that 80 percent of all business decisions utilize geographic data (Mennecke, 1997). It is very likely that these numbers are now even greater due to the prevalence of devices that can collect geo-referenced data, particularly GPS-enabled mobile computing platforms, such as smartphones or tablets.

Based on the geospatial information that has been collected by organization, researchers have found that an understanding of such geospatial data can lead to improved decision-making (Pick, 2004). To help businesses utilize the immense body of geospatial knowledge that has been, and continues to be collected, specialized tools have been developed. These systems are Spatial Decision Support Systems (SDSS) and Geographic Information Systems (GIS).

SDSS function much like Decision Support Systems (DSS), but are designed to allow business decision-makers to better understand the complexities of geospatial data. GIS allow experts to analyze and report geographic data. Often, a GIS will provide data to a SDSS. As tools evolve, GIS often offer SDSS functionality and vice versa. Particularly interesting is that these tools have evolved to allow non-geospatial expert users to easily perform functions using web-based versions of these tools. For example, Web-based real estate informational sources often include such tools allowing future home owners to visualize proximities between locations, such as a potential new home and a school.

As the volume of geographic and geographically-referenced data grows and organizations rely on geovisualization to present such data to business decision makers, it is imperative that all aspects of the decision-making process be fully understood allowing researchers and practitioners to develop optimization techniques. This paper improves our understanding of how geospatial reasoning ability impacts the ability of business decision makers to use geovisualized information to make business decisions.

There are several research questions related to geovisualization, decision performance and geospatial reasoning ability. First, can geospatial reasoning ability be measured practically? Second, does a higher geospatial reasoning ability moderate decision-making performance? Third, can specific geovisualization techniques allow a decision-maker without a strong geospatial reasoning ability to make sound decisions? This paper will address the first of these questions.

This paper begins with a literature review emphasizing the theoretical background and the current understanding of user characteristics, particularly spatial reasoning, on geospatial decision performance. Next, a research model and proposed hypotheses will be presented. A section describing the development of a measurement instrument follows this section. Then, two proposed experimental studies will be presented. Finally, limitations of the reviewed literature, future research suggestions and a conclusion will be presented.

## LITERATURE REVIEW

This section provides an analysis of reoccurring topics found in literature related to geovisualization and decision performance, along with literature exploring the effects of user characteristics on decision-making performance, with an emphasis on research related to spatial reasoning.

### Theoretical Background

The importance of visual information presentation has been explored by numerous researchers. For example, Vessey (1991) posits the Cognitive Fit Theory, which states that there are two types of information presentation, as well as two types of problem-solving tasks. Furthermore, it is suggested that when the problem representation matches the problem-solving task, higher quality decisions are made. The Cognitive Fit Theory has been referenced as a theoretical background, extended into other domains and validated in numerous empirical studies, such as Mennecke, Crossland and Killingsworth (2000), Smelcer and Carmel (1997) and Speier and Morris (2003). Extensions of Cognitive Fit Theory include work performed by Dennis and Carte (1998) which demonstrated that when map-based presentations are coupled with appropriate tasks, decision processes and decision performance are influenced. Additionally, Mennecke et al. (2000) expand on the Cognitive Fit Theory by determining the effects of subject characteristics and problem complexity on decision efficiency and accuracy. Speier (2006) presented a review of eight empirical research papers that tested for cognitive fit. This research discovered that all but one paper (Frownfelter-Lohrke, 1998) either fully or partially supported the Cognitive Fit Theory.

### Geovisualization

While geospatial data can be presented utilizing traditional methods such as tables, often unique relationships and causes contained within geospatial data are only apparent though geovisualization (Reiterer, Mann, Mußler and Bleimann, 2000). Geovisualization, or the visualization of geospatial or geospatially-referenced data, and its effect on decision-performance has been explored in several key works, including Crossland, Wynne and Perkins (1995), Smelcer and Carmel (1997), Speier and Morris (2003) and Dennis and Carte (1998).

### Decision Performance

Research measuring information presentation and its effects on decision performance utilize numerous measurement indicators; however, objective measures, such as decision-time and decision-accuracy, are the most common (Crossland et al., 1995; Dennis and Carte, 1998; Smelcer and Carmel, 1997; and Speier, 2006). Other indicators have included perceptions of decision-performance and even decision-regret (Hung, Ku, Ting-Peng and Chang-Jen, 2007; Sirola, 2003). Researchers exploring the relationship of geovisualization on decision-performance often include either task characteristics, user characteristics, or both, in their work (see Figure 1).

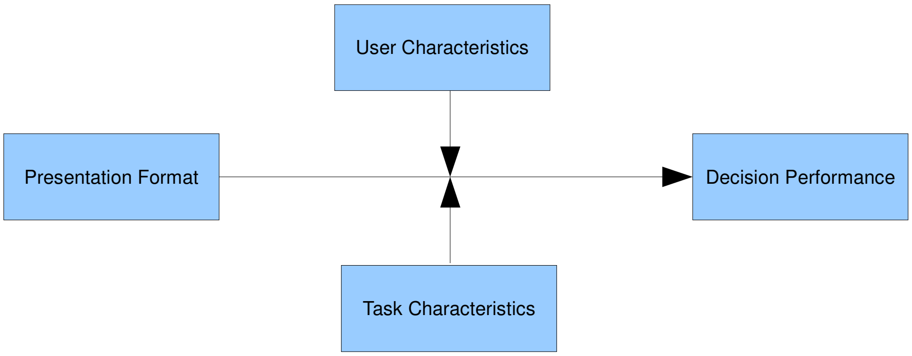

**Figure 1. The Influence of Presentation Format, User Characteristics and Task Characteristics on Decision Performance**

### User Characteristics

There is growing research into the effects of user characteristics, particularly context-based (Albert and Golledge, 1999; Slocum, Blok, Jiang, Koussoulakou, Montello, Fuhrmann and Hedley, 2001; Zipf, 2002) and cognitive-based (Mennecke et al., 2000; Speier and Morris, 2003). User characteristics explored have included gender (Albert and Golledge, 1999), previous experience with SDSS tools (Mennecke et al., 2000), as well as decision satisfaction, SDSS satisfaction, perceived decision quality, perceived decision efficiency, self-efficacy, motivation (Jarupathirun and Zahedi, 2001, 2007), and cognitive loads (Speier and Morris, 2003).

While the existing work on user characteristics has revealed important insights, research into the importance of spatial reasoning ability has produced conflicting results (Jarupathirun and Zahedi, 2007; Lee and Bednarz, 2009; Rafia, Anuarb, Samadb, Hayatib and Mahadzira, 2005; Smelcer and Carmel, 1997; Speier and Morris, 2003; Swink and Speier, 1999).

For example, Smelcer and Carmel (1997) discovered no significant relationships between spatial ability and decision-performance. However, the researchers pointed out that this might be because the task-characteristics may not have required the use of spatial ability from the research subjects. Additionally, Swink and Speier (1999) noted inconsistencies in prior research measuring spatial ability and called for additional research. Finally, Jarupathirun et al. (2007) revealed that spatial ability, as measured through spatial orientation ability and visualization ability had no effect on decision performance.

However, another corpus of research has found relationships between spatial ability and decision-performance. Swink and Speier (1999) revealed that experiments utilizing task-characteristics involving large problems with low data dispersion and user-characteristics of high spatial orientation, improved decision performance. Rafia et al. (2005) revealed that students with no spatial thinking ability had difficulty in courses requiring spatial thinking ability. Alternately, Lee and Bednarz (2009) discovered that students who completed courses utilizing geospatial tools gained greater geospatial reasoning ability as measured by a geospatial measurement exam developed by the authors. These conflicting results may be due to the nature of the spatial reasoning tests used (see Table 1).

| Study | Spatial Reasoning Test Used |
|---|---|
| Speier and Morris (2003) | S-1 (Spatial Orientation) |
| Swink and Speier (1999) | S-1 (Spatial Orientation) |
| Smelcer and Carmel (1997) | VZ-2 (Spatial Visualization) |
| Lee and Bednarz (2009) | New ‘Spatial Skills Test’ |
| Jarupathirun et al. (2007) | VZ-2 (Spatial Visualization)<br>S-1 (Spatial Orientation) |
| Albert and Golledge (1999) | Three Paper/Pencil Tests |

**Table 1. Spatial Reasoning Instruments Used in Examined Research**

## RESEARCH MODEL

This research will explore the definition of a construct measuring geospatial reasoning ability and developing an appropriate measurement scale.

### Spatial Reasoning Ability of Business Decision Makers

Lee and Bednarz (2009) emphasize that most of the spatial ability tests utilized in research involving geospatial ability are based on ‘table top,’ psychometric exams, such as those, which measure spatial orientation and spatial visualization. Indeed, many of the studies utilized various components of popular spatial skills tests (See Table 3). To overcome this limitation, Lee and Bednarz developed a test to measure true geospatial ability, which examines spatial reasoning at a geographic context-level. Furthermore, as various researchers utilized different tests of spatial ability, the results are not truly comparative. This finding is a key motivation for the development of a new construct and measurement tool that will allow future research to compare results and provide a more accurate measure which is context sensitive to both geographic-scale (task aware) and business decision-making (user aware.) Thus, a new construct, Spatial Reasoning Ability of Business Decision Makers (GRABDM), is introduced as a measure of an individual’s geospatial reasoning ability within the context of performing business decision-making.

### Substrata Identification

The first step in identifying dimensions of the GRABDM construct was to conduct a literature review of published works exploring spatial reasoning and geospatial reasoning. During this process, scholarly articles were scanned for key semantic content, which revealed four strong potential substrata of the GRABDM construct (see Table 2). To validate the results of this step, scholarly and industry experts were asked to validate each of the substrata and their definitions.

| Proposed Substrata | Definition |
|---|---|
| Geospatial Orientation and Navigation | The ability to determine one's position and direction in geographic space. |
| Geospatial Memorization and Recall | The ability to commit geographic concepts to memory and the ability to reconstruct these concepts. |
| Geospatial Visualization | The ability to form mental images of geographic space. |
| Geospatial Schematization | The ability to reduce complexity of geographic elements by converting to a scheme or outline. |

**Table 2. Proposed Substrata of Geospatial Reasoning Ability of Business Decision Makers**

### Hypotheses

The relationship between each proposed substratum and the GRABDM construct is explored in this section and visually presented in Figure 2.

Prior research has demonstrated that orientation and navigation are indicators of spatial ability. For example, Kozlowski and Bryant (1977) revealed that perceptions of individual's sense of direction reflected their spatial orientation ability. Also, Swink and Speier (1999) discovered a relationship between spatial orientation and decision-performance. Furthermore, Cherney, Brabek and Runco (2008) reported that spatial task performance may be influenced by self-perceptions of navigation ability. As spatial orientation and navigation appear to be an indicator of spatial ability, within a geospatial context we posit:

*Hypothesis* $H_1$*: Geospatial orientation and navigation ability is an indicator of geospatial reasoning ability.*

Additionally, prior research has demonstrated that memorization and recall are indicators of spatial ability. In their study, Lei, Kao, Lin and Sun (2009), discovered that subjects who were familiar with a landmark where more likely to locate these landmarks using a geospatial tool than landmarks that were unfamiliar. Furthermore, Miyake, Friedman, Rettinger, Shah and Hegarty (2001) discovered that the ability to memorize visiospatial concepts may influence spatial ability. Thus, we posit:

*Hypothesis* $H_2$*: Geospatial memorization and recall ability is an indicator of geospatial reasoning ability.*

Furthermore, prior research has demonstrated that visualization ability is an indicator of spatial ability. For example, Eisenberg and McGinty (1977) utilized a spatial visualization test to measure spatial reasoning ability. Additionally, Velez, Silver and Tremaine (2005) discovered that spatial ability is correlated to the ability of 3-dimensional visualization. Thus, we posit:

*Hypothesis* $H_3$*: Geospatial visualization ability is an indicator of geospatial reasoning ability.*

Finally, researchers suggest that by reducing the amount of information presented in geovisualization to only include essential information, decision-making performance can be improved. The benefits of such simplified maps is demonstrated by Agrawala and Stolte (2001) who collected feedback from over 2,000 users of a technology that emulates hand-drawn driving directions, which often emphasize essential information while eliminating nonessential details. Additionally, Klippel, Richter, Barkowsky and Freksa (2005) suggest that modern cartographers can successfully develop schematic maps which are simplified, yet sufficient representations. As the ability to effectively interpret such schematized geospatial information appears essential for business decision-makers utilizing geospatial information, we posit:

*Hypothesis* $H_4$*: Geospatial schematization ability is an indicator of geospatial reasoning ability.*

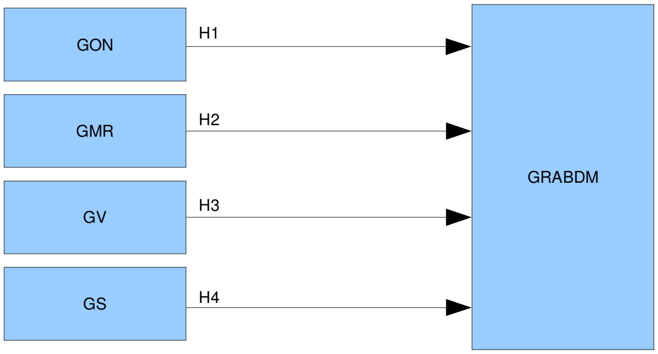

**Figure 2. Research Model**

## MEASUREMENT DEVELOPMENT METHODOLOGY

Although there has been tremendous growth of geospatial data within organizations and research has continually measured user characteristics, particularly spatial ability, the IS scholarship lacks an empirically-validated geospatial reasoning ability measurement scale. Thus, a comprehensive multi-step process was utilized to develop a multi-item scale with high reliability and high validity.

### Item Development

Due to the lack of existing measurement items for the new construct and its substrata, measurement items were developed utilizing key words from the literature and categorizing them into the substrata, then converting them into questions. The following tables present the initial measurement items of the proposed substrata of GRABDM, which include geospatial orientation and navigation (GON), geospatial memorization and recall (GMR), geospatial visualization (GV) and geospatial schematization (GS). To develop measurement items, the semantic terminology was derived from the substrata definitions and expert interviews.

The GON substratum is defined as 'the ability to determine one's position and direction in geographic space.' The following initial measurement items (see Table 3) are expected to measure the GON substratum.

| | |
|---|---|
| GON1 | In most circumstances, I feel that I could quickly determine where I am based on my surroundings. |
| GON2 | I can usually determine the cardinal directions by looking at the sky. |
| GON3 | I rarely get lost. |
| GON4 | Examining my surroundings allows me to easily orient myself. |
| GON5 | At any given point, I usually know where north, south, east and west lie. |
| GON6 | I find it difficult to orient myself in a new place. |
| GON7 | Knowing my current location is rarely important to me. |
| GON8 | I feel that I can easily orientate myself in a new place. |
| GON9 | Using a compass is easy. |
| GON10 | I rarely consider myself lost. |
| GON11 | I have a great sense of direction. |
| GON12 | I could easily navigate a course of '500 meters north and 500 meters east' using a magnetic compass. |
| GON13 | Knowing my current location is essential to determine where I am going. |
| GON14 | When driving or walking home, I am likely to choose a route that I have never taken. |

**Table 3. Initial Geospatial Orientation and Navigation Measurement Items**

The GMR substratum is defined as 'the ability to commit geographic concepts to memory and the ability to reconstruct these concepts.' The following initial measurement items (see Table 4) are expected to measure the GMR substratum.

| | |
|---|---|
| GMR1 | I am good at giving driving directions from memory. |
| GMR2 | I am good at giving walking directions from memory. |
| GMR3 | I can usually remember a new route after I have traveled it only once. |
| GMR4 | I don't enjoy giving directions, as I have trouble recalling the details needed. |
| GMR5 | I don't remember routes. |
| GMR6 | When revisiting a place I don't frequent often, I usually can remember how to get around. |
| GMR7 | After studying a map, I can often follow the route without needing to look back at the map. |
| GMR8 | When someone gives me good verbal directions, I can usually get to my destination without asking for additional directions. |
| GMR9 | After being a shown a map, it would be easy for me to recreate a similar map to memory. |
| GMR10 | After seeing a city map once, I am usually able to commit key landmarks and their locations to memory. |
| GMR11 | It would be easier to memorize a tabular list of states, instead of a map showing the states. |
| GMR12 | It would be easier to memorize capital cities from a map, instead of a table. |
| GMR13 | The best way to memorize the layout of a college campus is to study a map. |
| GMR14 | I could draw an approximate outline of my home country from memory. |

**Table 4. Initial Geospatial Memorization and Recall Measurement Items**

The GV substratum is defined as 'the ability to form mental images of geographic space.' The following initial measurement items (see Table 5) are expected to measure the GV substratum.

| | |
|---|---|
| GV1 | It is easy for me to visualize a place I have visited. |
| GV2 | I find it difficult to visualize a place I have visited. |
| GV3 | I can visualize a place from information that is provided by a map without having been there. |
| GV4 | When someone describes a place I form a mental image of what it looks like. |
| GV5 | I can visualize geographic locations. |
| GV6 | When someone describes a place, I have a difficult time visualizing what it looks like. |
| GV7 | When viewing an aerial photograph, I often visualize what the area looks like on the ground. |
| GV8 | I can visualize a place from an aerial photograph. |
| GV9 | I can visualize a place from a verbal description. |
| GV10 | I can visualize a place from a map. |
| GV11 | I can visualize what a future building might look like on an empty lot. |
| GV12 | When viewing a map, I often visualize what the area looks like on the ground. |
| GV13 | While reading written walking directions, I often form a mental image of the walk. |
| GV14 | Generally I prefer to memorize the mental images of a walk or drive, versus the written directions. |

**Table 5. Initial Geospatial Visualization Measurement Items**

Finally, the GS substratum is defined as 'the ability to reduce complexity of geographic elements by converting to a scheme or outline.' The following initial measurement items (see Table 6) are expected to measure the GS substratum.

| | |
|---|---|
| GS1 | I prefer maps that display key information clearly, such as transit maps. |
| GS2 | I prefer maps that include full-color aerial photography. |
| GS3 | I prefer simple, sketch-like maps. |
| GS4 | When looking at subway or transit maps, I can usually quickly find the routes I need to take in order to reach my destination. |
| GS5 | When giving directions it is easy for me to decide what is important enough to include and what to exclude. |
| GS6 | I prefer maps that only provide key information, even if they are not to scale. |
| GS7 | I prefer maps that only provide information necessary to accomplish my tasks. |
| GS8 | I prefer written walking directions that only include the most essential navigational elements. |
| GS9 | I prefer maps that show only the most essential information. |
| GS10 | I am better at interpreting maps that only provide necessary information. |
| GS11 | It is easy for me to ignore irrelevant information on a map and to focus only on necessary information. |
| GS12 | I prefer verbal driving directions that only include the most essential information to reach my destination. |
| GS13 | I like simple, clear maps. |
| GS14 | I prefer highly detailed maps that show more than just the basic information. |

**Table 6. Initial Geospatial Schematization Measurement Items**

### Pretest

Following the development of the initial GRABDM substrata measurement items, a pretest was conducted consisting of a categorization and prioritization exercise. For this pretest, ten business decision-makers were given five envelopes, each stating the name and definition of the substrata, as well as an envelope for items that did not fit the four substrata. Additionally, the participants were given index cards with each prospective measurement item and asked to both sort and categorize the items into the appropriate envelope. Based on the pretest results, measurement items which had a majority categorization agreement were retained and ordered based on the averaged ranks. As shown in Tables 7-10, the items resulting from the pretest were combined into a single instrument and a 7-point Likert scale (Likert, 1932) was added to measure agreement of each item.

| Initial Item | Sort Results | New Item Rank | Rank Results |
|---|---|---|---|
| GON1 | | GON3 | |
| GON2 | | GON11 | Remove |
| GON3 | | GON7 | |
| GON4 | | GON1 | |
| GON5 | | GON2 | |
| GON6 | | GON8 | |
| GON7 | Remove | | |
| GON8 | | GON5 | |
| GON9 | | GON9 | |
| GON10 | | GON6 | |
| GON11 | | GON4 | |

| | | | |
|---|---|---|---|
| GON12 | | GON10 | |
| GON13 | Remove | | |
| GON14 | Remove | | |

**Table 7. Pretest Results of Geospatial Orientation and Navigation**

| Initial Item | Sort Results | New Item Rank | Rank Results |
|---|---|---|---|
| GMR1 | | GMR2 | |
| GMR2 | | GMR4 | |
| GMR3 | | GMR1 | |
| GMR4 | | GMR8 | |
| GMR5 | | GMR6 | |
| GMR6 | | GMR9 | |
| GMR7 | | GMR3 | |
| GMR8 | | GMR5 | |
| GMR9 | | GMR7 | |
| GMR10 | | GMR10 | |
| GMR11 | | GMR13 | Remove |
| GMR12 | | GMR12 | Remove |
| GMR13 | | GMR11 | Remove |
| GMR14 | Remove | | |

**Table 8. Pretest Results of Geospatial Memorization and Recall**

| Initial Item | Sort Results | New Item Rank | Rank Results |
|---|---|---|---|
| GV1 | | GV4 | |
| GV2 | | GV7 | |
| GV3 | | GV2 | |
| GV4 | | GV6 | |
| GV5 | | GV1 | |
| GV6 | | GV13 | Remove |
| GV7 | | GV12 | Remove |
| GV8 | | GV8 | |
| GV9 | | GV5 | |
| GV10 | | GV3 | |
| GV11 | | GV14 | Remove |
| GV12 | | GV11 | Remove |
| GV13 | | GV10 | |
| GV14 | | GV9 | |

**Table 9. Pretest Results of Geospatial Visualization**

| Initial Item | Sort Results | New Item Rank | Rank Results |
|---|---|---|---|
| GS1 | | GS7 | |
| GS2 | | GS11 | Remove |
| GS3 | | GS1 | |
| GS4 | Remove | | |
| GS5 | | GS6 | |
| GS6 | | GS10 | |
| GS7 | | GS9 | |
| GS8 | | GS8 | |
| GS9 | | GS4 | |
| GS10 | | GS12 | Remove |
| GS11 | | GS2 | |
| GS12 | Remove | | |
| GS13 | | GS5 | |
| GS14 | | GS3 | |

**Table 10. Pretest Results of Geospatial Schematization**

### Pilot Test

Following the pretest, a pilot test of the research instrument was conducted. For the pilot test, 33 subjects were asked to complete an online survey, measuring the results of all 40 substrata measurement items. Additionally, the subjects were provided with an opportunity to provide input via open-ended questions designed to elicit feedback on the measurement items. The open-ended question responses will be semantically reviewed for additional opportunities of scale refinement. An Item Analysis performed using IBM SPSS Statistics 19 revealed either good or acceptable levels of Cronbach's alpha (Table 11) for each substratum, (Cronbach, 1951; Gliem and Gliem, 2003).

| Substrata | Cronbach's Alpha | N of Items |
|---|---|---|
| GON | .830 | 10 |
| GMR | .846 | 10 |
| GV | .835 | 10 |
| GS | .735 | 10 |

**Table 11. Pilot Test Substrata Reliability Statistics**

## FUTURE STUDIES

Based on the successful pretest and pilot, an exploratory study will be performed. For this study, a population consisting of business decision-makers and representative graduate and undergraduate students from a US research university will be asked to complete a survey. The results of this exploratory study will be used to further establish construct validity and to refine the measurement scale. To establish nomological validity, a confirmatory study will follow and empirically test the GRABDM construct within the context of a literature-based research model.

## DISCUSSION

Upon completion of the aforementioned study, a detailed discussion of the findings and their implications will be presented. As prior research has revealed conflicting results on the importance of spatial ability on decision-performance, particularly when utilizing geographic data, the results of this research will provide researchers with a stronger, context-specific measure of geospatial ability that can be extended into future research. Furthermore, the GRABDM measurement scale could be employed to extend studies related to usability of SDSS, GIS, as well as empirically measuring the effectiveness of various geovisualization techniques. In addition to providing researchers with a valid construct and measurement scale, this research will provide business leaders with a validated measurement tool to determine current and future employee's geospatial reasoning ability within the business context. The researchers feel that this ability will be an essential component for the successful interpretation of geovisualized data and will allow organizations to make better decisions from such data.

### Limitations and Future Research

While the current study attempts to establish an instrument, a future exploratory and confirmatory study will also be conducted in order to further establish the validity of the GRABDM construct. As the construct proposed in this research project will only be tested in highly controlled experiments to ensure strong internal validity, it will be essential that the construct be extended to ensure greater external validity. Due to this limitation, further refinement and validation of the measurement items must be performed. Research examples would include the application on real-world cases, as well as measuring the construct on current geospatial professionals, particularly those who work with business data and make business decisions, and comparing these results to average business decision makers.

## CONCLUSION

Literature has demonstrated that geospatial data is generally best presented in a geovisualized format to improve decision-making performance; however, the effects of geospatial reasoning are not yet fully understood. In response to conflicting results in the literature regarding the importance of spatial ability, a new construct measuring geospatial reasoning ability within a business context was proposed. Next, substrata of this construct were identified and a pretest was conducted to develop a measurement instrument for this new construct. As indicated in Table 11, a pilot test revealed strong reliability of the proposed substrata. The proposed construct and measurement scale will be evaluated in upcoming exploratory and confirmatory studies.

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