Foreword

Surveying Body of Knowledge

Surveying is one of the oldest professions and yet, today, it seems as if its perceived identity and distinctiveness have become less recognized and understood. In the past, the identity of the profession was soundly established and well defined. If someone needed to depict the real world on a map or to demarcate features on the earth, it was widely recognized that this is the function of the surveyor. Surveyors had the unique know-how, tools, skills and ability to fulfill this function. However, new technological developments and the emergence of the geo-spatial industry have eroded the recognition of the professional surveyor's exclusive abilities to define and represent on a map features on Earth.

In recent years, the surveying profession and the requirement for surveying licensure were challenged several times in different states and by other professional associations. In Alabama, a bill to loosen the requirements for surveying licensure was introduced after a city councilman claimed that "PVC pipes made everyone a plumber, the wire welder made everybody a welder, and GPS made everyone a surveyor." In New Jersey, a bill was introduced to allow civil engineers to qualify for licensure claiming that civil engineers have all the necessary knowledge and skills needed to ably function as surveyors. In New York, spatial data collection by unlicensed individuals was challenged by the surveying society. Finally, in a position paper by the GIS Certification Institute it was argued that "the practice of surveying should be defined narrowly" and that "associated state regulations should be narrow in scope, reflecting the limited footprint of survey practice within the geospatial field."

These developments and the ongoing challenge for surveyors to keep pace with newly introduced technology and measurement paradigms necessitate the development of the surveying body of knowledge. The challenge is not only to keep pace with the technical "know-how" but also with the theoretical "know-why". A true professional must understand and knowledgeably stand behind his/her actions. If surveyors claim that they are best qualified to collect precise data with GPS, they must demonstrate that they understand the theory of satellite positioning and GPS error analysis. To do that surveyors have to define that knowledge and make sure they acquire it.

A surveying body of knowledge will not only help the surveying profession to define its specialties within the geospatial industry but it will help educate other professionals and the public about the special values of surveying. A claim that civil engineers know everything that is needed to function as professional surveyors is not necessarily malicious and ill intended. Many civil engineers who took a surveying 101 course in college truly believe that they know everything needed to be known about surveying. Until a surveying body of knowledge is documented, it will be an uphill battle to challenge such claims.

In 2007, at the North American Surveying and Mapping Educators conference, a first paper on a surveying body of knowledge was presented (Greenfeld and Potts 2008). The paper discussed, in general terms, the need of a surveying body of knowledge and offered an outline for such a document. At the end of the conference, a resolution was passed to create a working group to develop a surveying body of knowledge. Subsequently, the CARE (Certification, Accreditation, Registration and Education) committee of ACSM (American Congress on Surveying and Mapping) recognized the need for a surveying body of knowledge and created the Surveying Body of Knowledge Committee. Later on, the ACSM congress passed a resolution to establish an ACSM committee to develop a surveying body of knowledge. Essentially the same individuals carried out the tasks of both committees. In 2009, at a follow-up North American Surveying and Mapping Educators conference, an entire session on the surveying body of knowledge was held, featuring five presentations on different topics. In the next two years, the committee held numerous conference calls and meetings to shape the content as well as the format of the surveying body of knowledge. The results of this effort are presented in this issue of *Surveying and Land Information Science.*

The surveying body of knowledge has six parts. The first part provides a macro level outline of the fundamental knowledge that a professional surveyor should possess to function effectively as a respected professional. The other five parts outline more specific, micro level knowledge in specialized fields of surveying. The five subsets of the surveying body of knowledge are in the areas of positioning, law, GIS, imagery and land development. There are many overlapping knowledge components between these surveying specialties. For example, data adjustments are required in positioning, imagery, GIS and, arguably, in law and land development. Legal issues are not confined to boundary surveying: they are present in GIS and land development as well. Our committee decided to allow such repetitions of knowledge areas in different specialty subsets of the surveying body of knowledge because they were deemed helpful in presenting each subset as a complete and separate unit. In this issue, all six components of the surveying body of knowledge are presented.

The first paper classifies the knowledge areas and topics by level of specialization and describes. the educational requirements needed to acquire that knowledge. As in the other papers, the different depth of knowledge and the level of competency needed in the various surveying specialties are defined. The rationale for this attention to detail is that a practicing surveyor and a scholar who researches and develops new theories or tools for surveying will have different educational background.

The other five papers in the issue provide the details of the positioning, law, imagery, GIS and land development bodies of knowledge. Each paper has an introduction, a rationale for the specific body of knowledge, a description of knowledge areas and the specific units/topics that make up the knowledge area, a table depicting the level of knowledge requirements, and a summary. The level of knowledge requirement is classified as basic (required from all surveyors), specialist (required from surveyors specializing in a given aspect of surveying), and scholar (surveyors conducting research and development in academia or industry).

The Committee on the Surveying Body of Knowledge was created to reflect a balance between theory and practice. About one half of the members of the committee were from the academia and one half were practicing professional land surveyors and individuals involved with surveying equipment development. The committee members who actively participated in the development of the surveying body of knowledge were Jim Bethel, Peter Borbas, Earl F. Burkholder, Bob Burtch, Bob Dahn, Wendy Lathrop, Jeff Lucas, Joe Paiva, and myself serving as chair of the committee.

Joshua Greenfeld
Chair, Surveying Body of
Knowledge Committee

Surveying Body of Knowledge

Joshua Greenfeld

ABSTRACT: A profession is founded on knowledge, skills, and education. The knowledge, skills, and education required to practice within a profession should be defined in a body of knowledge of that profession. This is the first edition or the first comprehensive attempt to define the surveying body of knowledge. This work was initiated about three years ago, by the American Congress on Surveying and Mapping and the North American Surveying Educators organization. A special body of knowledge committee was established to carry out this task. The committee decided to develop a six part surveying body of knowledge. The first is a general body of knowledge, termed as the macro level body of knowledge which is presented in this paper. The other five specific detailed subset (micro level) bodies of knowledge in the areas of positioning, imagery, geographic information systems, law, and land development. The paper introduces the philosophical and conceptual considerations on which the body of knowledge was founded and provides details on the macro level body of knowledge.

KEYWORDS: Surveying, education, professionalism

Introduction

As positioning technologies evolve and mapping capabilities become prevalent through the global positioning system (GPS), geographic information systems (GIS), Google Earth, and other technologies there is a growing perception that "everyone can do surveying and mapping." Such an attitude could have an adverse impact on the surveying profession. The phenomenon of technology enabling individuals to perform tasks that once required special expertise is not unique to surveying. It happens especially in cases where there is a lack of understanding of the added value of performing that task by a professional expert. One of the reasons for the misguided assumption that having a GPS receiver, a GIS software, and perhaps a few hours of training is enough to perform surveying is a lack of understanding of what a surveyor does and what is the knowledge base and skills on which the profession is founded. Therefore, it is of utmost importance that we examine closely what makes an occupation a profession and what are the characteristics of the surveying profession that would necessitate its existence.

According to the Australian National Organization of Professional Associations, the definition of a profession is:

> *A profession is a disciplined group of individuals who adhere to ethical standards and hold themselves out as, and are accepted by the public as possessing special knowledge and skills in a widely recognized body of learning derived from research, education and training at a high level, and who are prepared to apply this knowledge and exercise these skills in the interest of others.*
> (Professions Australia 1997)

The surveying profession is not different from any other occupation that is defined as a profession. Consequently, the knowledge and skills that are required to become a professional land surveyor have to be determined based on the above principles.

Before describing how a body of knowledge can be developed it is beneficial to distinguish between skills and knowledge. Skills presuppose a certain level of "know-how" but not necessarily of "know-why". A skilled person can perform a task very well by following a given set of procedures that are well tested to provide the necessary results. A skilled person may not be able to explain why these procedures work or how they work. All such a person knows is that he/she is able to get things done very well. Knowledge, on the other hand, is the foundation on which the "why" can be explained. It provides the reason why a given set of actions produce the required results. With knowledge, not only are we able to follow procedures to get things done but also find better ways to obtain the same (or better) results. Knowledge also allows professionals to assess the quality of their work, respond adequately to

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problems that may arise, change standards and regulations, and adapt to new technologies. Thus, the goal of developing a body of knowledge for a profession is not merely to outline the skills needed to perform various tasks but define the theoretical knowledge needed to function as a professional and promote real-world understanding of that knowledge.

There are two primary approaches to defining a body of knowledge. The first is to delineate the skills, attitudes, and knowledge that will enable an individual to develop the understanding and abilities necessary to become and function as a professional, an expert in the field. The other is to define a professions' body of knowledge is to compile a detailed list of the theories, methodologies, technologies, and procedures that professionals have to master to engage in professional practice. It can be argued that each of these approaches has its merits but using both approaches is even more advantages. If both are used the body of knowledge will consist of a macro level body of knowledge which provides a definition of those conceptual, long-term requirements that enable professionals to keep pace with knowledge and technology, and a micro level body of knowledge that defines the current needs for professional practice.

A first attempt to define the body of knowledge for surveying on a macro level was presented in a recently published paper (Greenfeld and Potts 2008). The paper outlines the more general body of knowledge for surveying which is consistent, to some extent with the outcome assessment approach introduced by ABET (Accreditation Board for Engineering and Technology) in Criteria 2000 (ABET 2000). In the ABET approach, objectives and outcomes are to be defined without prescribing the details of the implementation. A similar approach was adopted by the American Society of Civil Engineers (ASCE) to develop their body of knowledge for civil engineers (ASCE 2004; 2008) and by other professional societies.

As mentioned earlier complementing the macro definition of the surveying body of knowledge with a micro level surveying body of knowledge can be advantageous. The micro level definition is also desired because of the recurring challenges the surveying profession is facing from others such as civil engineers or GIS practitioners. Defining the body of knowledge for surveying at the micro level would help the profession to specify its uniqueness and the value it adds to many geospatial activities.

One available potential source for micro level surveying knowledge areas is the one compiled by the U.S. National Council of Examiners for Engineering and Surveying (NCEES). NCEES periodically conducts a survey of the practice of surveying in the U.S., and the results are used to determine the type of knowledge that must be mastered to qualify as a surveyor-in-training or as a professional surveyor. The fundamentals of surveying and professional practice licensing exams are based on this knowledge base (NCEES). This approach requires periodic updating of the knowledge base to capture changes in technology and other changes in the way surveying is being practiced. It "reacts" to what is happening in the practice of surveying rather than anticipating where the profession is or should be heading. However, as the objective of a body of knowledge is not only to address current needs but also to provide a foundation for a life-long career in surveying, it cannot be based solely on the NCEES knowledge base.

The micro level approach for defining the body of knowledge was adopted by other professional bodies such as the Association of American Geographers (AAG) and the University Consortium for Geographic Information Science. These organizations have developed the "*GIS and Technology body of knowledge*" published in 2006 (AAG 2006). The micro level surveying body of knowledge generally follows the format of the GIS and Technology body of knowledge.

In this paper, the approach for developing the surveying body of knowledge will be described. It was designed to include both, the macro level body of knowledge and the micro level body of knowledge. The focus of this paper is the macro-level surveying body of knowledge; the detailed micro level bodies of knowledge are presented in the other five papers published in this issue.

Building a Body of Knowledge

There are several decisions that have to be made when constructing a body of knowledge for a profession. The first is the level of detail. A body of knowledge can be defined in general terms, such knowledge of math, law, communication, business, etc., without explicitly itemizing the subcomponents of these knowledge components. Describing a body of knowledge by its components yields a macro level of the body of knowledge. The ASCE published their body of knowledge using this concept. But, as mentioned earlier, a body of knowledge can be defined by the specific knowledge areas that inform different aspects of professional activities, as is the case with AAG's body of knowledge for GIS. The Surveying Body of Knowledge Committee decided to develop a hybrid body of knowledge which includes both of these approaches.

The second major decision that had to be made was how to define the scope and different aspects of the professional activities of surveyors as well as the required knowledge base to support these activities. Our committee decided to adopt the International Federation of Surveyors (FIG) resolution on the activities performed by surveyors (FIG 2004). According to FIG:

> *The surveyor's professional tasks may involve one or more of the following activities, which may occur either on, above, or below the surface of the land or the sea and may be carried out in association with other professionals.*

1. The determination of the size and shape of the earth and the measurement of all data needed to define the size, position, shape, and contour of any part of the earth and monitoring any change therein.
2. The positioning of objects in space and time as well as the positioning and monitoring of physical features, structures, and engineering works on, above, or below the surface of the earth.
3. The development, testing, and calibration of sensors, instruments, and systems for the above-mentioned purposes and for other surveying purposes.
4. The acquisition and use of spatial information from close range, aerial, and satellite imagery and the automation of these processes.
5. The determination of the position of the boundaries of public or private land, including national and international boundaries, and the registration of those lands with the appropriate authorities.
6. The design, establishment, and administration of geographic information systems (GIS) and the collection, storage, analysis, management, display, and dissemination of data.
7. The analysis, interpretation, and integration of spatial objects and phenomena in GIS, including the visualization and communication of such data in maps, models, and mobile digital devices.
8. The study of the natural and social environment, the measurement of land and marine resources, and the use of such data in the planning of development in urban, rural, and regional areas.
9. The planning, development, and redevelopment of property, whether urban or rural and whether land or buildings.
10. The assessment of value and the management of property, whether urban or rural and whether land or buildings.
11. The planning, measurement, and management of construction works, including the estimation of costs.

Based on the above, the committee decided to create five subsets of the surveying body of knowledge. These are:

- Positioning body of knowledge – including Geodesy, GPS, and other field surveying data collection
- GIS body of knowledge – including mapping and cartography
- Imagery body of knowledge – including photogrammetry, remote sensing, and other image/sensor-based technologies such as laser scanners
- Law body of knowledge – including boundary, real property, and business law
- Land development body of knowledge – including construction, planning, and development of urban/rural/regional areas

Definitions of Level of Competence

Each of the knowledge areas has breadth and depth aspects. Therefore, knowledge, skills, and attitudes can exist at many different levels of capability and usefulness. For example, the level of knowledge required to perform positioning with GPS depends on the application and on the level of accuracy sought. A surveyor specializing in construction applications will not need to possess the same level of GPS knowledge as a surveyor specializing in deformation analysis with GPS. Nevertheless, as surveyors they have to gain some level of knowledge of GPS to qualify for surveying practice. Such levels of knowledge have to be defined for every element of knowledge in the body of knowledge. Anderson and Krathwohl (2001) suggest six levels of acquired knowledge depth and competence:

- **Remembering:** Retrieving, recognizing, and recalling relevant knowledge from long-term memory.
- **Understanding:** Constructing meaning from oral, written, and graphic messages through interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining.

- **Applying:** Carrying out or using a procedure through executing or implementing.
- **Analyzing:** Breaking material into constituent parts, determining how the parts relate to one another and to an overall structure or purpose through differentiating, organizing, and attributing.
- **Evaluating:** Making judgments based on criteria and standards through checking and critiquing.
- **Creating:** Putting elements together to form a coherent or functional whole; reorganizing elements into a new pattern or structure through generating, planning, or producing.

It would be difficult to associate each knowledge component with these six levels of acquired knowledge and competence. Therefore, a more simplified definition of competence levels were implemented for the macro level surveying body of knowledge. Greenfeld and Potts (2008) suggested three levels of competence. They are:

- Level 1 (***Recognition***) represents a reasonable level of familiarity with a concept. At this level, the surveyor is familiar with a concept, but lacks the knowledge to specify and procure solutions without additional expertise. For example, a surveyor might *recognize* that a particular GIS project poses significant implementation challenges without having the expertise to devise improved implementation or design alternatives.
- Level 2 (***Understanding***) implies a thorough mental grasp and comprehension of a concept or topic. Understanding typically requires more than abstract knowledge. For example, a surveyor with an *understanding* of boundary law should be able to identify and to communicate legal issues arising from a practical case study.
- Level 3 **(Ability)** is a capability to perform with competence. A surveyor with the ability to design and implement a particular project can take responsibility for the project, identifying all the necessary aspects of the design, and match objectives with appropriate technological solutions. As a surveyor grows professionally, his/her abilities also develop so that more challenging and difficult problems can be solved.

A further classification of required competence is related to the level of engagement in particular aspects of surveying. A person who elected to pursue a career related to surveying has several career options. He/she can become a practicing professional land surveyor, a hardware/software developer in the hardware/software company, or a researcher in an academic institution. He/she can specialize in boundary surveying, photogrammetry, GIS, or construction surveying. Each of these selections results in a different type, level, or category of competency. Consequently, one has to consider another categorization of knowledge and competency levels, one that is a function of the level of involvement in a particular area of surveying and the level of specialization in that area. The categories of surveying knowledge and competency are listed in Table 1. The micro level surveying body of knowledge will be categorized according to these three levels of knowledge.

The Macro Level Body of Knowledge

The macro level surveying body of knowledge (Figure 1) is based on the 11 outcomes required by ABET, plus four additional outcomes that are specific to surveying. The four additional outcomes are comprised of a single depth outcome, and three breadth outcomes. These outcomes are described in Greenfeld and Potts (2008). Each outcome is presented in the form of outcomes and commentaries. The outcomes collectively outline the necessary breadth of knowledge, skills, and attitudes required of an individual aspiring to enter the practice of surveying at the professional level.

Thus, a contemporary surveyor must demonstrate:

1. **An ability to** apply knowledge **of mathematics, science, and engineering/applied science/technology.** (ABET (a))

   Commentary: A technical core of knowledge and breadth of coverage in mathematics, science, and technology is stressed in this outcome. Underlying the role of the professional surveyor as the master of spatial information creator, analyzer, integrator, and

Category	Knowledge Level
Basic	Breadth of knowledge that everyone in the surveying profession should have
Specialization/expertise	A deep knowledge with ability to perform with confidence
Scholarly	Levels of knowledge with ability of research and development and to lead the profession to its future challenges

Table 1. Knowledge categories.

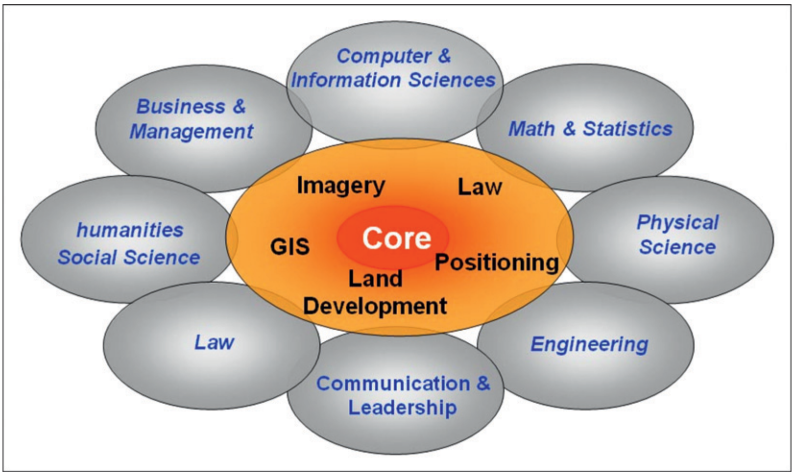

Figure 1. The macro level surveying body of knowledge.

technical leader, the knowledge for this outcome should include most of the following: mathematics through linear algebra, probability, statistics and statistical testing, physics, economics, geo-spatial representation, and information technology. In imparting the common technical core, it will enable the surveyor to understand the fundamentals of several recognized major surveying areas.

2. An ability to design and conduct **experiments,** as well as **analyze** and **interpret** data. (ABET (b))
Commentary: Surveyors commonly design and conduct field work, gather data, process observations and evidence, and then analyze and interpret the results. Professional surveyors should be able to do this in at least one of the current major surveying areas. Examples are geodetic control, field based mapping, imagery based mapping, boundary surveys, GIS, etc.

3. An ability to **design** a system, component, or process to meet desired needs. (ABET (c))
Commentary: Design methodology and process elements include problem definition, scope, methodology, means, analysis, creativity, synthesizing alternatives, iteration, regulations, codes, and safety. Other important design elements are bidding on projects, estimating costs, and interaction between planning, design, and execution. Understanding large-scale systems is important, including the need to integrate information, organizations, people, processes, and technology.

4. An ability to function on **multi-disciplinary teams.** (ABET (d))
Commentary: Professional surveyors should be able to lead teams as well as participate as a member of a team. This requires understanding of team formation and evolution, personality profiles, team dynamics, collaboration among diverse disciplines and/or within sub disciplines of surveying, problem solving, and time management and being able to foster and integrate diversity of perspectives, knowledge, and experiences.

5. An ability to identify, formulate, and solve **Surveying problems.** (ABET e)
Commentary: Assessing situations to identify surveying problems, formulate alternatives, and recommend feasible solutions is an important aspect of the professional responsibilities of a professional surveyor.

6. An understanding of **professional and ethical responsibility.** (ABET (f))
Commentary: The professional surveyor is to hold paramount the welfare of the public. A thoughtful and careful weighing of alternatives when values conflict is crucial to the responsible conduct of surveying. Therefore, a professional surveyor needs to demonstrate an understanding of and a commitment to practice according to the fundamental principles of ethics and the codes of professional conduct.

7. An ability to **communicate** effectively. (ABET (g))
Commentary: Effective communication includes listening, observing, reading, speaking, and writing, and requires understanding of the fundamentals of interacting effectively with technical and nontechnical individuals or audiences, in a variety of settings. A professional surveyor needs to be versatile with communication and presentation tools such as word processing, spreadsheets, slide presentations, graphics, visualization, the world wide web, and other means of communication.

8. A broad education necessary to understand the **impact of Surveying solutions** in a global and societal context. (ABET (h))
Commentary: A professional surveyor needs to appreciate, from historical and contemporary perspectives, culture, human and organizational behavior and their impacts on society. This includes history of land ownership and the heritage of the surveying profession.

9. A recognition of the need for, and an ability to engage in, **life-long learning.** (ABET (i))
   Commentary: Life-long learning mechanisms available for personal and professional development include additional formal education, continuing education, professional practice experience, active involvement in professional societies, community service, coaching, mentoring, and other learning and growth activities. Professional development can include career management, increasing discipline knowledge, understanding business fundamentals, contributing to the profession, self-employment, achieving licensure, and specialty certification. Personal development can include developing understanding of and competence in goal setting, personal time management, communication, delegation, networking, leadership, and effecting change.
10. A knowledge of **contemporary issues.** (ABET (j))
   Commentary: To be effective, professional surveyors should appreciate the relationship of surveying to critical contemporary issues such as multicultural globalization of surveying practice; raising the quality of life around the globe; the growing diversity of society; and the technical, environmental, societal, political, legal, economic, and financial implications of surveying and spatial information projects.
11. An ability to use the techniques, skills, and modern **Surveying tools** necessary for surveying (engineering) practice. (ABET (k))
   Commentary: This includes the role and use of appropriate positioning and information technologies, contemporary analysis and design methods, and applicable standards, as practical problem-solving tools to complement knowledge of fundamental concepts. Also included is the ability to select the appropriate tools for solving different types and levels of problems.

In addition to the above 11 ABET required outcomes, the four additional outcomes below may be considered.

12. An ability to apply knowledge in a **specialized area related to Surveying.**
   Commentary: A professional surveyor should become an expert or specialist in an area of surveying or in an area related to surveying. Examples of specialized technical areas, that might be selected, are legal aspects of surveying, mapping (field- or image-based), visualization, GIS, high order surveying, and Geodesy. Specializations in nontraditional fields such as computer science, geography, and spatial representation and statistics are also appropriate.
13. An understanding of the elements of **supervision and project management.**
   Commentary: Professional surveyors often supervise and carry out projects. Project management essentials include project manager responsibilities, defining and meeting client requirements, contract negotiation, project work plans, scope and deliverables, budget and schedule preparation and monitoring, equipment, safety, interaction among professionals from various disciplines, quality assurance and quality control, and dispute resolution processes.
14. An understanding of **business and public policy and administration fundamentals.**
   Commentary: The professional surveyor typically functions within the private sector but also within the public sector. This requires at least an understanding of business, public policy, and public administration fundamentals. Important business fundamental topics as typically applied in the private sector include legal forms of ownership, organizational structure and design, income statements, balance sheets, economic decisions, finance, marketing and sales, billable time, overhead, and profit. Essential public policy and administration fundamentals include the political process, public policy, laws and regulations, funding mechanisms, public education and involvement, government-business interaction, and the public service responsibility of professionals.
15. An understanding of the **role of the leader and leadership principles.**
   Commentary: Leading, in the private and public arena, which differs from and complements managing, requires broad motivation, direction, and communication knowledge and skills. Attitudes generally accepted as being conducive to leadership include commitment, confidence, curiosity, entrepreneurship, integrity, judgment, persistence, positiveness, and sensitivity. Desirable behaviors of leaders, which can be taught and learned, include earning trust, trusting others, formulating and articulating vision, communication, honesty and integrity, rational thinking, openness, consistency, commitment to organizational values, and discretion with sensitive information.

All 15 outcomes can be summarized as:

A technical core of knowledge and breadth of coverage in mathematics, science, and technology.

- The knowledge in mathematics must be beyond algebra and trigonometry. Calculus and linear algebra must be included to understand error theory and least squares adjustment. As surveying technology evolves, redundant observations are easier to obtain. Redundant observations are the most important vehicle to supervise, monitor, and assess the quality of work done by technicians.
- The knowledge in statistics includes statistical testing and blunder detection theory. As before this is an indispensable means for quality control and quality assurance.
- Computer science
- Knowledge in physics and other science is important to understand how modern surveying tools work. Understanding how the equipment works will make it easier to understand how to work with the equipment, and how to minimize and evaluate possible error. This will distinguish the surveyor from "GPS made everyone a surveyor."
- Information science and information technology especially as it relates to geo-spatial information. Almost all a surveyor does is related to spatial information systems.
- Basic knowledge of the science behind Geodesy (ellipsoids, geoids, map projections, geometric representation of the earth, height systems, gravity), image- and sensor-based mapping systems (terrestrial, air or space borne).

Law, ethics, and professionalism

- A surveyor needs to have a broad knowledge of the law beyond the obvious, namely, boundary law. The knowledge should include elements of the legislative process, courts and the court system, statuary law, administrative law, the legal process, real estate law, business law, legal forms of ownership, etc. This will help the surveyor to be familiar with framework in which he/she functions.
- The surveyor is to hold paramount the welfare of the public. A surveyor needs to demonstrate an understanding of and a commitment to practice according to the fundamental principles of ethics and the codes of professional conduct.

Communication, history, social science, and contemporary issues

- A surveyor needs to be versatile with communication and presentation tools such as word processing, spreadsheets, slide presentations, graphics, visualization, the world wide web, and others to present himself in a professional manner.
- To be effective, a surveyor should appreciate the relationship of surveying to critical contemporary issues such as the technical, environmental, societal, political, legal, economic, and financial implications of surveying and spatial information projects.

Business, economics, and management

- This knowledge is needed because a surveyor commonly runs his/her own business or a surveying department in a larger consulting firm or in a surveying department in a public company or in local government. It is also needed because a contemporary surveyor should be able to manage projects, contracts, people, budgets, schedules, finance, marketing and sales, billable time, overhead, profits, etc.

At least one in-depth specialty in surveying law, positioning, GIS, image-based mapping, land development, or other.

The in-depth knowledge required to perform in these technical specialties will be described in the other papers of this issue which focus on micro level body of knowledge.

Some surveying practitioners will question the relevance of certain elements of the knowledge areas and attitudes to surveying practice listed. Others will agree that while knowledge and skills are integral parts of well rounded surveying education, attitude development lies outside of the education/knowledge milieu. Some will claim that an understanding of ethical responsibility (Outcome 6) is sufficient to address the attitudes issue. Finally, some will argue that attitudes are important but believe that attitudes, and the values they reflect, are largely fixed by the time a young person enters college. Nevertheless, attitude teaching and learning opportunities can be created during the education and experience process (Elms 1966). Such opportunities can occur via case studies of exemplars and failures, and the demeanor of faculty, professional mentor's and professional peer's.

Education for Surveyors

While a recognized body of knowledge is a key component of the definition of a profession there is another, equally important, element in the definition of a profession, namely, that a professional person is "*accepted by the public as possessing special knowledge and skills in a widely recognized body of* *learning derived from research, education, and training at a high level.*" In other words, not only the body of knowledge is accepted by the public as special qualification that warrants recognition of uniqueness, but that it has to be coupled with education or training at a high level. Note that the requirement is not just for any education but for a high level of education. It is hard to argue against the assumption that "high level" means at least a baccalaureate degree in the area that teaches the body of knowledge. There are many professions that require an advanced degree as a minimum qualification and others that are considering making it a requirement (e.g., ASCE). It would be hard to find a respected profession that does not require a minimum of a four-year degree.

One persistent challenge for the surveying profession in the U.S. is the lack of mandatory four-year-degree college education for licensure across the nation. Experience gained under a licensed surveyor for any length of time may not necessarily encompass the minimum body of knowledge outlined here. It the lack of formal college education requirement is also an obstacle in our quest for the recognition of the surveying profession as a profession of the highest standing. Graduates completing a surveying curriculum in a four-year degree program are, however, likely to become competent and highly respected professional surveyors because they will possess some level of the breath and depth of education described in the macro level body of knowledge. Graduates from a typical surveying program who have an option to select additional in-depth classes or take graduate classes in specific technical areas such as law, land surveying, photogrammetry, GIS, or other could become specialists in these areas.

Surveyors should strive even higher. Surveyors should strive to become surveying scholars. To be a surveying scholar, one will need to have an advanced degree, preferably (but not necessarily) in surveying/geomatics or in another related discipline. The path to becoming a surveying scholar could lead via earning a related or unrelated undergraduate degree (e.g., science, math, and engineering) before reading for an advanced degree in surveying/geomatics. The definition of a profession embraces both options because a body of knowledge is derived from education and training as well as research. A profession that is truly professional should thus include a cadre of researchers who came from within the profession and helped develop new theories, methodologies, tools, and technologies that keep the profession relevant throughout the times. Surveying cannot afford to rely on electrical engineers and computer scientists to pave the way to its future. This effort must be led by surveying scholars.

In light of this fact, one can distinguish among three roles of surveyors. The first is a general practitioner who performs routine surveying tasks such as boundary surveying, construction surveying, and other standard mapping tasks. The second role of surveyors is that of a specialist. A specialist could be a surveyor who serves as an expert witness in court, a surveyor who performs high accuracy deformation surveys and analysis, a surveyor who specializes in image analysis, or a surveyor who designs and manages GIS systems. The third role of surveyors is that of a scholar. A scholar surveyor performs research within an academic surveying program, as a member of faculty or is engaged in applied research at a hardware/software company which serves not only the surveying community but perhaps the entire geo-spatial industry. The educational requirements for the three roles of surveyors are shown in Table 2. (R indicates that the education is required and P means that it is preferable.)

To keep up with new conceptual and technological developments professional surveyors have to engage in life-long professional education. A prerequisite for effective professional education is a strong foundation in law, humanities (especially communication), and many elements of science (mathematics, computer, social, business, etc.). This is yet another argument for requiring a minimum education standard for entry into the profession.

	Undergraduate Degree	Professional Education	Post Baccalaureate Certification	Graduate Degree
General practitioner	R	R	P	—
Specialist	R	R	R	P
Scholar	R	P	P	R

R = Requires; P = preferred.

Table 2. Educational requirements for surveyors.

Summary and Conclusions

A profession is founded on knowledge, skills, and education. There are two important aspects of a profession; the first is the body of knowledge that defines it and the other is education. The body of knowledge for a given profession can be developed on a macro level or on a micro level, or both. Developing both levels of a body of knowledge has the advantage of defining not only the contemporary needs of the profession but also the long-range, technology-independent lifelong body of knowledge. Education is important because it enables the acquirement of the knowledge and raises the respect of the public for the profession. In this paper the macro level body of knowledge was presented together with the levels of education needed for the different roles of surveying practice. The micro level surveying body of knowledge will be presented in other papers.

The macro level body of knowledge consists of general education and of surveying-specific education. Mathematics, statistics, basic science, humanities, management, communication, and general law and ethics comprise education areas that underlie any successful practice of surveying. The knowledge required to perform surveying tasks as defined by FIG can be acquired through surveying-specific education. This knowledge will allow the professional surveyor to be successful as a general practitioner.

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GIS Body of Knowledge for Surveying

Joshua Greenfeld

Introduction

The acronym GIS can be interpreted to mean Geographic Information Systems or Geographic Information Science. The first interpretation treats GIS as a tool while the second interpretation assumes GIS to be a distinct scientific/professional discipline. A mature and informed interpretation is that it is both. GIS is an information system based on spatial and other sciences which can be implemented using software for spatial analysis. Many professionals, including surveyors, who are used to working with computer aided drafting (CAD) systems were mistakenly introduced to GIS as being "just a CAD tool with a database". The science, the analysis, and the knowledge discovery aspects of GIS were hardly mentioned. This has limited the understanding of what GIS is and has contributed to tensions between professional surveyors and GIS mappers over professional practice infringements, basically over who is permitted to do what. To circumvent some of this tension it is beneficial to define what GIS is in the broader sense, define the complete GIS body of knowledge, and then define the distinctiveness of the surveying profession and its specific body of knowledge as it relates to GIS.

The GIS body of knowledge was defined and published in a collaborative effort by the Association of American Geographers (AAG) and the University Consortium for Geographic Information Science (UCGIS) (AAG 2006). Because the definition of the GIS body of knowledge has already been established, it would be counterproductive to attempt to develop a new and different GIS body of knowledge. If surveying is to become allied with the GIS industry, it should define itself within the consented definitions of that industry. The AAG/UCGIS definition of GIS is very broad, spanning over many disciplines and professional activities beyond the scope of surveying. Therefore, rather than redefining the GIS body of knowledge, we need to focus on those parts that address the role of the surveying profession in the geospatial world in a manner consistent with an inclusive surveying body of knowledge.

In this paper, the relationship between GIS and surveying will be firmly established. This should help surveyors gain a better insight into GIS and enable the GIS community to get a better understanding of the role surveying plays in GIS. Next, an overview of the AAG/UCGIS GIS body of knowledge will be presented, followed by a detailed description of the GIS body of knowledge specifically formulated for surveying.

Because the surveying GIS body of knowledge is extensive in breadth and depth, the knowledge areas and specific topics in the knowledge areas will be categorized by the level of the surveyor's involvement in GIS activities. Some surveyors are occasional users of GIS while others are scholars involved in GIS research and development. Each of these categories of surveyor will need a different degree of knowledge in certain aspects of the GIS body of knowledge. The level of education required to arrive at a given level of competence and involvement in each category will vary as well. Consequently, any delineation of the roles of surveyors in GIS needs to be accompanied by a definition of the levels of competencies and education required to enable surveyors be effective in GIS.

Surveying and GIS

The first step in creating a GIS body of knowledge for surveying is to establish the linkage between GIS and surveying and to define the role of surveying in GIS and the role of GIS in surveying. Since the dawn of civilization, surveyors have been viewed by society as professionals with expertise in measuring, analyzing, and representing, on a map, the spatial features of the surface of the earth. Until recently these activities required special skills that were uniquely possessed by surveyors. With the advent of electronic positioning devices and computer software, some aspects of the surveyors' professional uniqueness have diminished. New and old professions have begun performing some of the activities that once were

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in the domain of surveying. In fact, some of the traditional surveying activities are currently defined under the large umbrella of GIS. For example, Chrisman (2002) defines GIS as: The organized activity by which people:

- **Measure** aspects of geographic phenomena and processes;
- **Represent** these measurements, usually in the form of a computer database, to emphasize spatial themes, entities, and relationships;
- **Operate** upon these representations to produce more measurements and to discover new relationships by integrating disparate sources; and
- **Transform** these representations to conform to other frameworks of entities and relationships.

According to Chrisman these "core" activities reflect the larger context (institutions and cultures) in which these people carry out their work. In turn, the core GIS activities may influence these structures (in which they carry out their work). The four core activities and their context are shown in Figure 1 as rings or layers.

Chrisman's definition of GIS illustrates the overlap and the indistinctness between the many activities of surveying and those of GIS. The four inner layers of core activities (measure, represent, operations and transformation) in his definition are an authentic description of surveying. The four inner layers can be interpreted in a broader perspective as well, but at the same time it fits the description of surveying. Some members of the surveying community have the tendency to overlook the two outer layers (institutional and social/cultural contexts) of Figure 1. It is worthwhile reexamining this given the global nature of today's business environment. At the same time, some members of the GIS community tend to underestimate the importance of the core inner circles of Figure 1. Regardless of these different perceptions of GIS, it is clear that a significant part of the surveying body of knowledge is symbiotic with the body of knowledge of GIS.

GIS Competencies

Another way to describe the relationship between surveying and GIS is to examine the competencies required to perform GIS. In 2003 the Geospatial Workforce Development Center developed a Geospatial Technology Competency Model that specifically identifies the roles, competencies, and outputs for the geospatial technology industry (Gaudet, Annulis, and Carr 2003). This competency model (which was developed following a concern expressed by the U.S. Department of Labor that there is a shortfall of knowledgeable and skilled professionals in the Geospatial industry) concludes that: "For geospatial technology professionals to be successful in today's marketplace, it is critical to understand that the knowledge, skills, and abilities required for their jobs include a blend of technical, business, analytical, and interpersonal competencies" (Gaudet, Annulis, and Carr 2003, p. 25). This conclusion is consistent with ABET's (Accreditation Board for Engineering and Technology) (ABET 2000) accreditation philosophy and the general precepts of the surveying body of knowledge outlined in Greenfeld and Potts (2008). The elements of the Geospatial Technology Competency Model competency model are shown in Table 1.

The GIS&T Body of Knowledge

The Geographic Information Science and Technology (GIS&T) Body of Knowledge was developed in 2005 by AAG/UCGIS and was intended to serve as a reference for curriculum planners at institutions of higher and continuing education. The motivation for the development of a GIS Model Curricula and subsequently the GIS&T body of knowledge was to make certain that students are well prepared for the demands of the workplace. These demands are presented in Table 1, and other studies such as the "Strawman report" (Marble et al. 2003).

The GIS&T body of knowledge has a three tier hierarchical outline, comprised of "*knowledge*

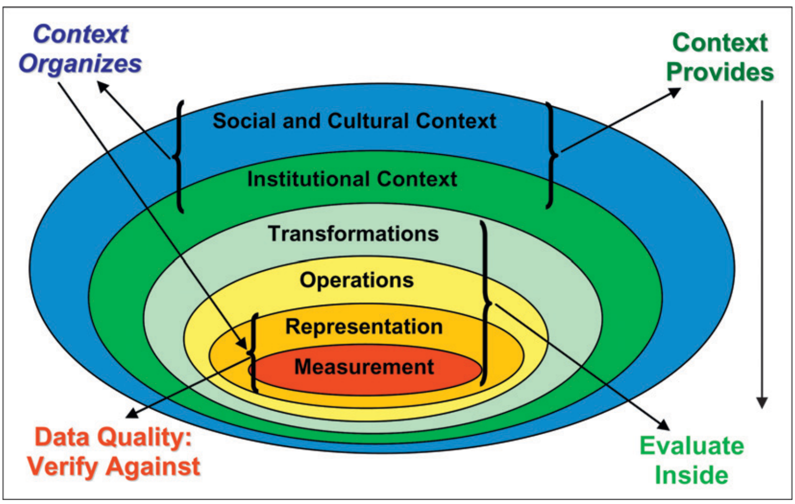

Figure 1. The definition of GIS based on Chrisman (2002).

TECHNICAL COMPETENCIES	BUSINESS COMPETENCIES
Ability to assess relationships among geospatial technologies	**Ability to see the "big picture"**
Cartography	Business understanding
Computer programming skills	Buy-in/advocacy
Environmental applications	**Change management**
GIS theory and applications	**Cost benefit analysis/ Return on investment**
Geological applications	Ethics modeling
Geospatial data processing tools	Industry understanding
Photogrammetry	Legal understanding
Remote sensing theory and applications	Organizational understanding
Spatial information processing	Performance analysis and evaluation
Technical writing	**Visioning**
Technological literacy	**INTERPERSONAL COMPETENCIES**
Topology	Coaching
ANALYTICAL COMPETENCIES	**Communication**
Creative thinking	Conflict management
Knowledge management	**Feedback skills**
Model building skills	Group process understanding
Problem-solving skills	**Leadership skills**
Research skill	Questioning
Systems thinking	**Relationship building skills self-knowledge/self-management**

Table 1. Thirty-nine competencies required for success in the geospatial technology profession. **Boldface** type indicates core competencies.

areas," "*units,*" and "*topics.*" Knowledge areas represent discrete clusters of knowledge, skills, and application areas that define the breadth of the GIS&T domain. The 10 knowledge areas identified in the GIS&T Body of Knowledge are:

- Analytical Methods
- Conceptual Foundations
- Cartography and Visualization
- Design Aspects
- Data Modeling
- Data Manipulation
- Geocomputation
- Geospatial Data
- GIS&T and Society
- Organizational and Institutional Aspects

These ten knowledge areas of the GIS&T body of knowledge are comprised of more than 330 topics organized into 73 units. Each topic is defined in terms of formal educational objectives which can be used for instructional activities and for deriving assessment instruments. Units are designated as either "core" or "elective." Core units are those in which all graduates of a degree or certificate program should be able to demonstrate some level of mastery. Elective units represent advanced topics that imply some degree of specialization in a particular knowledge area.

The Surveying GIS Body of Knowledge

The surveying GIS body of knowledge is, to a large extent, a subset of the comprehensive GIS&T body of knowledge. However the philosophical intent and the organization of the knowledge areas are different. The surveying GIS body of knowledge is not directly intended to outline a curriculum of an undergraduate or graduate academic program in surveying. Rather, it lists and narrates the topics that surveyors should master at various levels of GIS involvement. In addition, instead of listing the knowledge areas in alphabetical order (the order followed in the AAG/UCGIS document), the knowledge areas listed here follow the stepwise required knowledge in the progression towards the establishment of a GIS.

As stated earlier, the development of the surveying body of knowledge is rooted in the 11 functions of the surveyor defined by FIG (International Federation of Surveyors). Two of those functions feature GIS activities. Consequently, the knowledge areas of the surveying GIS body of knowledge presented here, will follow the spirit of the FIG definitions (FIG 2004). The two relevant functions in the FIG definition are:

1. The design, establishment, and administration of geographic information systems and the collection, storage, analysis, management, display, and dissemination of data.
2. The analysis, interpretation, and integration of spatial objects and phenomena in GIS, including the visualization and communication of such data in maps, models, and mobile digital devices.

Breaking down these functions into knowledge areas led to the definition of nine knowledge areas. The nine knowledge areas are:

- Conceptual Foundations
- Data Modeling
- Design Aspects
- Geospatial Data
- Data Manipulation
- Analytical Methods
- Cartography and Visualization
- Legal and Ethical aspects of GIS
- Management and Organization Aspects

The first knowledge area is conceptual foundations. It was selected to be the first knowledge area because it provides the underpinning objectives of a GIS, and the mental adjustments necessary to understand the context of GIS. This is very important, especially for those surveyors who were made to believe that GIS is a CAD system with a database. The conceptual foundations include spatial thinking and thinking spatially (NRC 2006), and understanding the translation of real world phenomena into a meaningful computerized representation.

The second knowledge area, data modeling, is the bridge between the philosophical concepts of GIS and the manifestation of these concepts as data models in a database. The next three knowledge areas are concerned with the actual building process of a GIS. The first step is designing the GIS, followed by collecting data and ending with organizing the data (called data manipulation) in the most usable form.

The goal of a GIS is to derive information and new knowledge from data. This is done using analytical methods and analytical tools. New knowledge can be derived by employing methods ranging from simple comparisons of datasets to complex statistical correlation between multiple sources of information. All of these operations fall under the knowledge area of analytical methods. Raw data and newly derived knowledge has to be communicated to the user.The user can be a surveyor, a scientist, or a decision maker. GIS communicates its findings with cartographic and visualization tools. Hence, the next GIS knowledge area is cartography and visualization.

Finally, a GIS system is established by people for people, in a particular institutional circumstance and in a given political environment. This means that there are legal and ethical issues that may arise based on how people compile, store, and handle the sensitive information in a given organization. Legal and ethical issues may also arise while deriving information from GIS or disseminating it via GIS. Managing a GIS in any organization requires additional skills and knowledge beyond the technical aspects of GIS. These issues are covered in the knowledge areas dealing with legal and ethical aspects of GIS and management and organization aspects of GIS.

The nine knowledge areas are described in more detail in the following sections. Each knowledge area is explained in general terms, followed by a detailed account of specific topics. When appropriate, specific examples are provided for each topic.

Knowledge Area: Conceptual Foundations

The conceptual foundation of GIS is rooted in spatial thinking that finds meaning in the shape, size, orientation, location, direction, or trajectory, of objects, processes, or phenomena, or the relative positions in space of multiple objects, processes or phenomena. Spatial thinking is required in modeling the real world into spatial, spatiotemporal, and semantic components, and in performing meaningful analysis with GIS. Spatial thinking requires an understanding of the fundamental philosophical and scientific views on the nature of space and time in the context of geographic phenomena. It also requires an understanding of the mathematical and graphical models that formalize these concepts, including set theory, algebra, and semantic nets which serve as the "language" of spatial tasks. The conceptual foundation knowledge area is compromised of the following:

Unit 1. Philosophical and Social Perspective

Geographic information is observed, comprehended, organized, and used in human processes, with both personal and social influences. Therefore, models of geographic information should be grounded in a sound understanding of human perception, cognition, memory, and behavior, as well as human institutions.

Unit 2. Domains of Geographic Information

Geographic phenomena and information are described in terms of space time and properties. Their formal representation includes the following:

- Four basic dimensions or shapes used to describe spatial objects (i.e., points, lines, regions, and volumes);

- Location of spatial objects in terms of Cartesian coordinates, address, description, or linear referencing system;
- Temporal frames of reference: linear and cyclical, absolute and relative, continuous and discrete, terms such as after, longer, change, and movement;
- Stevens' four levels of measurement (i.e., nominal, ordinal, interval, and ratio);
- Attribute domains include: continuous and discrete, qualitative and quantitative, absolute and relative; and
- Some phenomena, such as aesthetics in the landscape, cannot be adequately represented by formal attributes.

Unit 3. Elements of Geographic Information

The basic elements with which geographic phenomena are described are entities, events, and processes. Entities are commonly defined by a perceptual process (e.g., edge detection) which could pose difficulties when the entity has ill-defined edges. The conceptualization of entities is also scale dependent. Events are things that happen to entities and the reasons why entities change. Events and processes cause changes of states for a given phenomena through time.

Unit 4. Geospatial Relationships

Geographic information not only models phenomena but the relationships between them. This can include relationships between entities, between attributes, and between locations. Such information enables the utilization of a spatial perspective to relate disparate subjects, such as climate and economy. Relationships take various forms, including:

- Metric relationships such as distances and directions;
- Topological relationships to describe: disjoint, overlap, within, and intersect;
- Lineage and inheritance relationships;
- Categorical relationships;
- Structural relationships such as networks and other graph based structures;
- Spatial patterns and distribution; and
- Regional relationship based on functional, cultural, physical, administrative, and other regional divisions.

Unit 5. Imperfections in Geographic Information

There are two types of imperfection: vagueness and uncertainty. Vagueness (i.e., fuzziness, imprecision, and indeterminacy) is generally caused by human simplification of a complex, dynamic, ambiguous, subjective world. Uncertainty is usually the result of imperfect measurement processes. Both of these impact all forms of geographic information, including space, time, attribute, categories, and even existence. Mathematical models of fuzzy sets, error propagations, and statistical concepts of probability are used to determine and quantify the imperfections.

Unit 6. The Origin/History of GIS

The origin and evolution of mapping concepts and spatial modeling throughout history. The advancement of information technology and digital mapping into a comprehensive GIS.

Knowledge Area: Data Modeling

Data modeling is the representation of formalized spatial and spatio-temporal reality through data models, and the translation of these data models into data structures that are capable of being implemented within a computational environment (i.e., within a GIS). Examples of spatial data model types are discrete (object based), continuous (location based), dynamic, and probabilistic.

Unit 1. Basic Storage and Retrieval Structure

This unit deals with Basic data structure terminology (e.g., records, field, parent/child, nodes, and pointers) and data structures for storing and retrieving geospatial data (e.g., arrays, linked lists, binary trees, hash tables, and indexes).

Unit 2. Database Management Systems

For the Relational Database Management Systems (DBMS) this includes:

- Basic terms used in relational database management systems (e.g., tuple, relation, foreign key, Structured Query Language (SQL), relational join);
- Normalization;
- Data modeling using entity-relationship diagrams and their translation into relational tables;
- Shortcomings of standard relational tables in representing geospatial data; and
- Extensions and standards of the relational model designed to represent geospatial and other semi-structured data, such as stored procedures,

Binary Large Objects (BLOBs), nested tables, abstract data types, and spatial data types.

For Object-Oriented DBMS it includes:

- Basic elements of the object-oriented paradigm, such as inheritance, encapsulation, methods, and composition;
- The properties of object orientation that allow for combining and generalizing objects; and
- The understanding of the advantages and disadvantages of object-oriented databases compared with relational databases, focusing on representational power, data entry, storage efficiency, and query performance.

Unit 3. Tessellation Data Models (e.g., Raster Data Model)

A tessellation of the plane is a collection of plane figures that fills the plane with no overlaps and no gaps. Tessellations can be constructed of regular (e.g., grid, hexagons) and irregular (e.g., triangulated irregular network (TIN)) geometric shapes.

- Representation and quality of the analysis depends on the resolution of the tessellation.
- The raster model is a type of tessellation.
- Tessellations can be efficiently represented by quadtrees, hextrees, R-trees, and pyramids.

Unit 4. Vector and Object Data Models

Vector data models represent discrete entities by delineating points, lines, boundaries, and nodes as sets of coordinate values with associated attributes. The object-based view goes beyond traditional vector models representing information in a more human-centered and natural way.

Vector data can be represented in a GIS with:

- The "spaghetti" model (which lists sets of connected points);
- Topological model (composed of point, arc, and polygon tables); and
- Network model and linear referencing model.

In object model stores geometric data and attribute data are stored in the same location.

Unit 5. Three-Dimensional, Temporal, and Uncertain Phenomena Data Models

Some GIS aspects such as temporal change, uncertainty, three-dimensional (3D) phenomena, and integrated multimedia cannot be adequately handled with traditional raster and vector data models.

Knowledge Area: Design Aspects

The design aspect knowledge area focuses on the design of applications and databases for a particular need. Design activities fall into three general classes:

1. Application Design addresses the development of workflows, procedures, and customized software tools for using geospatial technologies and methods to accomplish both routine and unique tasks that are inherently geographic.
2. Analytic Model Design incorporates methods for developing effective mathematical and other models of spatial situations and processes. The design of the analytic model is often influenced by decisions that are made about data models and structures.
3. Database Design concerns the optimal organization of the necessary spatial data in a computer environment to efficiently sustain a particular application or enterprise.

Unit 1. The Scope of GIS System Design

Scope can be described in terms of:

- Scales, ranging from systems put together to solve a single problem to permanent enterprise databases; and
- Objectives (scientific research, resource management, decision support, etc).

Unit 2. Project Definition

Project definition includes:

- Problem definition in terms of institutional mission;
- Planning for design in terms of identifying collaborating people, schedule, and funding;
- Application/user assessment in terms of potential users, existing spatial tasks, and assessing the potential for improving the efficiency and/or effectiveness of existing and new activities; and
- Requirements analysis for user-centered solutions, workflow, and information flow that serves enterprise-wide needs.

Unit 3. Resource Planning

Resources are needed for a variety of elements of the system, including:

- Design, software purchase, data cost, labor and management, hardware, and facilities;
- Outsourcing versus in-house development, pilot studies, and reporting to decision makers; and

- Funding sources for the implementation phase and long term maintenance.

Unit 4. Database Design

Database design in this context is a three-step process:

- *Conceptual model*—A formal model in which every entity being modeled in the real world has a corresponding object in the model. It describes the semantics of some phenomena and represents a series of assertions about its nature.
- *Logical model*—The logical model organizes data in terms of a particular data management technology. For example, if a relational DBMS is used, it includes the full population of attributes and those attributes must be defined in terms of their domains or logical data types (e.g., character, number, date, pict).
- *Physical model*—An actual physical model of how the logical model is implemented in a particular computerized system.

Several standard modeling and software tools exist to aid database design, including modeling tools such as E-R (entity Relationship) diagrams, extended E-R diagrams, UML (unified modeling language), and XML (Extensible Markup Language), and others.

Unit 5. Analysis Design

Analysis design includes the identification of particular applications that require analytical modeling (not data modeling), identification of the sequence of operations and statistical/mathematical methods (or procedures) appropriate for particular applications, and the formalization of the procedures and their implementation in an appropriate environment (e.g., GIS software, software development environment).

Unit 6. Application Design

Application design is the development of customized software.

Unit 7. System Implementation

System implementation is the actual creation of the system from the design. Implementation includes creating an implementation plan in terms of specific tasks (e.g., data transformation, database implementation, testing, quality assessment, and system deployment), implementation schedule, and budget.

Knowledge Area: Geospatial Data

Geospatial data are the fuel that drives the GIS engine. They include measurements of locations and attributes of phenomena at or near the Earth's surface. Geospatial data may have spatial, temporal, and attribute (descriptive) components, as well as associated metadata. Data may be acquired from primary data sources (GPS, field surveys and surveying, remote sensing, etc.) or secondary data sources (digitizing and scanning analog maps, etc.).

This knowledge area is intimately related to other parts of the surveying body of knowledge especially those dealing with positioning and imagery. Specific knowledge components in the geospatial data knowledge area are:

Unit 1. Earth Geometry

Earth geometry can be approximated by:

- Modeling the shape and dimensions of Earth's surface
- Using different datums to approximate the shape and dimensions of the Earth; and
- Constructing the geoid.

Unit 2. Georeferencing Systems

Codes used to compute distances, areas, and volumes; to navigate; and to predict how and where phenomena on the Earth's surface may move, spread, or contract. In GIS they include the following:

- Point-based coordinate systems specify locations in relation to point of origin. Locations are defined in terms of geographic coordinate system, 3D Cartesian reference system, plane coordinate system (state plane, UTM (Universal Transverse Mercator)), or other.
- Tessellated referencing systems specify locations hierarchically, as sequences of numbers that represent smaller and smaller subdivisions of two- or three-dimensional surfaces that approximate the Earth's shape. An example for such a reference system is the quadtree.
- Linear referencing systems specify locations in relation to distances along a path from a starting point.

Unit 3. Datums

Datums define the geometric relationship between a location on the surface of the earth and its coded position. Examples of the most commonly used datums include: Horizontal and Vertical datums.

Unit 4. Map Projections

- Map projections are plane coordinate grids that have been transformed from geographic (spherical or ellipsoidal) coordinate grids using mathematical formulae. Inverse projections transform plane coordinates to geographic coordinates.
- In general, map projections are classified according to the developable surface used (plane, cone, or cylinder) and the geometric property preserved (equidistance, equivalent, conformal, or compromise).
- Different projections produce different distortion patterns that have to be understood and accounted for.
- How to select an appropriate map projection for particular uses is critical.

Unit 5. Land Partitioning Systems

Parcels can be referenced in an unsystematic form (e.g., metes and bounds land description) or in a systematic form (e.g., United States Public Land Survey System). Because parcel-based GISs are particularly common, knowledge of these systems from their historical evolution perspectives and from their current utilization is paramount. This topic is extensively covered in this document in the legal body of knowledge.

Unit 6. Data Quality

The ultimate standard of quality is the degree to which a geospatial data set is fit for use in a particular application. That standard varies from one application to another. In general, however, the key criteria are how much uncertainty is present in a data set and how much is acceptable. Judgments about fitness for use may be more difficult when data are acquired from secondary rather than primary sources. Aspects of data quality include geometric accuracy, thematic accuracy, resolution, and precision.

- Geometric accuracy or positional accuracy is a measure of closeness of the recorded position compared with the true position. It is computed in terms of standard deviations (e.g., FGDC (Federal Geographic Data Committee) standard, ASPRS (American Society for Photogrammetry and Remote Sensing) standard, or dilution of precision) or compliance to a standard (e.g., Map Accuracy Standard, geodetic control standards).
- Thematic accuracy is the accuracy of quantitative attributes and the correctness of non-quantitative attributes, and of the classifications of features and their relationships. It is normally computed using a misclassification matrix counting the number of misclassified attributes or by employing spatial autocorrelation techniques.
- Resolution is the smallest possible change of features or attributes that can be detected. There are different types of resolutions such as spatial resolution, thematic resolution, radiometric resolution, and temporal resolution. Resolution is affected by the sampling and resampling processes.

Data quality is also determined by error propagation which calculates the accumulation of all the contributing error committed during the measurement process.

Unit 7. Spatial Data Compilation

Methods for compiling geospatial data include:

- Traditional land surveying methods;
- Land records;
- Global Positioning Systems;
- Digitizing existing maps using a tablet digitizer, on-screen digitization, scanning, and automated vectorization techniques;
- Aerial imaging and photogrammetry; and
- Satellite based remote sensing.

Unit 8. Field Data Collection

Field data collection involves the *in situ* measurement of physical and demographic phenomena occurring at particular locations and times. Parameters of field data collection process include:

- Sample size–the minimum number and distribution of point samples for a given study area and a given statistical test of thematic accuracy;
- Sample type–including random, systematic, stratified random, and stratified systematic unaligned sampling strategies;
- Sampling intervals or sampling rates–sampling strategy used to investigate some of the temporal or other patterns; and

- Field data technologies for special data collection applications such as tracking moving objects or collecting data on the move.

Unit 9. Metadata, Standards, and Infrastructures

The documentation of data resources is termed "metadata". A typical metadata document contains the following sections:

- General identification information;
- Data quality information;
- Spatial Data Organization Information;
- Spatial Reference Information;
- Entity and Attribute Information;
- Distribution Information; and
- Metadata Reference Information.

Examples of standards for metadata include those developed by FGDC and IOS (International Organization for Standardization) 19115.

Knowledge Area: Data Manipulation

The manipulations of spatial and spatio-temporal data involve three general classes of operation:

- Transformation into different formats (i.e., vector to raster, raster to vector, projections, etc.) that facilitate subsequent analysis;
- Generalization and aggregation that affect the accuracy and integrity of the data used for analysis; and
- Transaction management that allows for the tracking of changes, versioning, and updating without loss of the original data.

The knowledge of how particular data types respond to changes in format, organization, scale, resolution, and quality (error propagation) is paramount to the ability to perform modeling and spatial analysis.

Unit 1. Representation Transformation

There are different forms of data structures, data models, projections, and other forms of geospatial data representation. These differences present both opportunities and challenges for analysis and modeling. The ability to transform one representation to another, in a manner that maintains the integrity of the information as much as possible, can enhance the analysis and visualization of geospatial data. Transformations include the following:

- Coordinate transformations–2D, 3D, or geographic coordinates using affine, similarity, Molodenski, Helmert, Polynomial, rubbersheeting, and other transformation methods.
- Data model conversions–raster to vector, vector to raster, and digital elevation model to TIN.
- Data interpolation using techniques such as nearest neighbor, bilinear, bicubic, etc. and resampling.

Unit 2. Generalization and Aggregation

Generalization and aggregation are classic cartographic operations. In the context of GIS it is associated with scope, volume, detail, and resolution of the geospatial data rather than with map scale. Generalization and aggregation are applied not only to geometric features (such as points, lines, and areas) but also to attributes (classification into fewer or broader classes, redistricting, transformation into ratios which yields ordinal data, etc.). Special attention is required when aggregating individual spatial entities to issues such as: privacy, security, proprietary interests, data simplification, etc.

Unit 3. Change Management of Geospatial Data

Archiving History of Change

In many circumstances, such as with data pertaining to land records, both spatial entities and their attribute data undergo frequent and often profound changes. Complete cataloging of these changes requires that the initial conditions, the new conditions, and any intermediate changes and methods of change be explicitly cataloged. Management of change can include the following:

- Keeping track of changes via versioning;
- Data reconciliation techniques;
- Editing privileges and priorities;
- Rollback techniques; and
- Preservation of consistent data.

Knowledge Area: Analytical Methods

A primary objective of GIS is to derive new information or new knowledge from geospatial data. This is done with data analysis by applying analytical, geo-statistical, or other geo-computational methods on the data. Data analysis seeks to understand both first-order (environmental) effects and second-order (interaction) effects. There are two main approaches for deriving results from geospatial data:

- Data-driven techniques (exploration of geospatial data) to derive summary descriptions

of data, evoke insights about characteristics of data, contribute to the development of research hypotheses, and lead to the derivation of analytical results; and
- Model-driven analysis to create and test geospatial process models.

It is imperative not to merely use these methods but also to understand the underlying theory. Therefore, this knowledge area requires knowledge and skills in mathematics, statistics, and computer programming.

Unit 1. Query Operations and Query Languages

The most basic form of GIS analysis is founded in set theory and performed utilizing Structured Query Language (SQL). Common spatial queries are:
- Selecting features based on location or spatial relationships;
- Searching for a specific spatial or temporal relationship; and
- Extracting all point objects that fall within a polygon.

Unit 2. Geometric Measures

Geometric measures are measures of distances, directions, shapes, areas, proximity, and adjacency/connectivity.
- A distance or length between two points can be defined in Euclidean space, Grid (Manhattan) space, Network space, projection space, or spherical space. Computing distances in different spaces will probably yield different values when compared to the actual distance obtained in the real world. Distance can be used to assess separation between points or to construct the spatial weight matrix.
- A direction is a measure of orientation in space. It is expressed in terms of Azimuth, Bearings, or Angles. Direction is calculated differently in vector and raster space. Computing direction in different geometric spaces (Euclidean, spherical, or projection) may yield different results.
- A shape measure can be applied to a polygon or to a set of data points to form a cluster. The shape of a cluster is typically defined by a minimum enclosing rectangle or by a convex hull.
- The area of a polygon calculated in a GIS will most probably be different than the actual area in the real-world. The calculated area is affected by the representation space (vector, raster, plane, spherical, projected, etc.) of the real-world feature.
- The proximity is a measure of the strength of the spatial relationship. Distance decay can be used to represent the strength of the spatial relationship. Distance decay is an appropriate representation in analyzing spatial relationships such as shopping behavior or property values but inappropriate for spatial relationships such as distance education, commuting, or telecommunications.
- Adjacency and connectivity are the ultimate measure of proximity. They represent topological relationships that occur when neighboring features share a common boundary (adjacency) or a common node (connectivity). Adjacency and connectivity can be recorded in matrices.

Unit 3. Basic Analytical Operations

These include buffer, spatial overlay, and neighborhood.
- A buffer is an analysis used for identifying areas surrounding a geographic feature. A buffer operation can be applied to point, line, or polygon features, in vector or raster space.
- A spatial overlay is a process of combining spatial information from two or more datasets to derive a new dataset consisting of same/new spatial boundaries. Boolean logic (e.g., union, intersection, dissolve, merge) is used in this process.
- A neighborhood can be defined as the smallest area possessing predefined characteristics. Neighborhoods can be defined by Thiessen-Voronoi proximity polygons and/or Delaunay triangulation. Map algebra operations (local, focal, zonal, and global) can be used to create neighborhoods. Neighborhood statistics (minimum, maximum, and focal flow) can be computed using a moving window in raster datasets.

Unit 4. Basic Analytical Methods

Basic analytical methods include point pattern analysis, density estimation or kernel density estimation, spatial cluster, and spatial interaction, and others.
- Point pattern analysis is a process to determine if there is a tendency of points (events) to exhibit a systematic pattern over an area as opposed to being randomly distributed. Some of the methods used for point pattern analysis

are: mean/median center, standard distance (and standard deviation), quadrat counts, nearest neighbor distance, G, F, and K function analysis, and statistical hypothesis tests based on methods such as the Independent Random Process/Chi-Squared Result (IRP/CSR) method.
- Density estimation or kernel density estimation is a process of estimating density of occurrences of events around a given point as a function of a radius (bandwidth) and a kernel *k* (e.g., a bivariate probability density function).
- Spatial cluster analysis is the process of identifying and grouping points or common grid cells into meaningful spatial findings (e.g., hot-spots). Different clustering methods (such as K-means, Fuzzy C-means, and Isoclass) use varying logic to find clusters.
- Spatial interaction is used to estimate the flow of people, material, or information between locations in geographic space. Models used for this analysis include: the classic gravity model, the unconstrained spatial interaction model, the production constrained spatial interaction model, the attraction constrained spatial interaction model, and the doubly constrained spatial interaction model.
- Other advanced analyses include multidimensional attributes analysis, multicriteria evaluation, and the analysis of the relationship between spatial processes and spatial patterns (e.g., tracks the changing location of particles through space).

Unit 5. Analysis of Surfaces

Analysis of surfaces is sets of techniques and tools used to derive useful information from continuous surface data. Examples of analysis of surfaces include:

- Calculating surface derivatives such as slope and aspect and slope points that constitute peaks, pits, and passes;
- Interpolation of surfaces using algorithms such as inverse distance weighting, bicubic spline fitting, and kriging (Other algorithms are used to convert irregular point elevation data into a regular grid or contours. Ridgelines and streamlines can (or should) be used to augment the interpolation process.);
- Intervisibility and viewshed analysis; and
- Friction surfaces or the cost of traveling through the surface, or resistance to travel across the surface to calculate the east-cost paths.

Unit 6. Spatial Statistics

Spatial statistical analysis is used for the testing of hypotheses about the nature of spatial pattern, dependency, and heterogeneity. Tools for statistical inferences from geospatial data include:

- Graphic methods are used for constructing a variety of graphs and plots to identify statistical characteristics of a set of spatial data. Commonly used graphic plots are: scatter-plots, histograms, box-plots, and q–q plots.
- Stochastic processes assume pure random spatial process. For statistically based spatial analysis it is important to distinguish between isotropic and anisotropic process and to understand the intrinsic stationarity assumption.
- A spatial weights matrix that quantifies the spatial relationship between features is used in a similar way weights are used for non spatial variables. In general, the spatial weights matrix is constructed based on adjacency or proximity.
- Spatial association is a measure of random, uniform, or clustery patterns. Measures of spatial association can be computed globally (e.g., K-function, Moran's I, Geary's C) and locally (e.g., LISA (local indicators of spatial autocorrelation), the G statistics).
- Bayesian methods, where prior or new knowledge is introduced to augment the classical statistical analysis. Some methods for computing Bayesian statistics are: Monte Carlo and the Markov-Chain Monte Carlo methods.
- Outliers have a detrimental affect on analysis. They should be identified and removed from the dataset. Techniques that can be used to examine outliers are: tabulation, histograms, box plots, correlation analysis, scatter plots, local statistics, etc.

Unit 7. Geostatistics

Geostatistics covers a variety of techniques used to analyze continuous data (e.g., rainfall, elevation, and air pollution) based on sampled data. The sampling schemes can be design-based or model-based and the analysis and predictions can be made using variograms, semivariograms, autocorrelation, or kriging.

Unit 8. Geocomputation

Some geographical systems can be difficult to model or analyze well with traditional statistical approaches due to a combination of data complexity, invalid assumptions, and computational demands. Geocomputational methods are often drawn from machine learning and simulation research and include a variety of methods designed to simulate, model, analyze, and visualize a range of highly complex, often nondeterministic, nonlinear problems. Methods include, but are not limited to, cellular automata, neural networks, agent-based models, genetic algorithms, and fuzzy sets.

Unit 9. Data Mining

Data mining is the process of finding pattern or knowledge discovery in very large datasets. Spatial data mining follows similar general data mining functions, with the end objective to find patterns or new knowledge in geography. Data mining approaches include: summarization/characterization, clustering/categorization, feature extraction, and rule/relationships extraction. Spatial statistics, analytical reasoning, visual representations, and interaction techniques used in spatial data mining. In addition, artificial intelligence analysis techniques of pattern recognition and matching are also employed.

Unit 10. Network Analysis

Networks are an efficient way to model many types of geographic data, including transportation networks, river networks, and utility networks, etc. A network or a graph is a set of connected edges and vertices. Network analysis encompasses a wide range of procedures, techniques, and methods based in graph theory. Graph theory contains descriptive measures (such as connectivity, adjacency, capacity, and flow) and indices (such as alpha, beta, or gamma indices) of networks. Analytical functions of network analysis include least cost (shortest) path algorithm (Dijkstra's algorithm, K-shortest path algorithms), flow modeling, traveling salesman problem, the Chinese postman problem, accessibility modeling, optimization and location-allocation modeling, and other classic transportation problems such as optimal routing and facility location.

Knowledge Area: Cartography and Visualization

Cartography and visualization primarily relate to the visual communication of geospatial data and of the results of geospatial analysis. This knowledge area is as old as surveying and map making and traditionally was allied with surveying. With the advent of new data collection technology, computer science, and the prevalence of the Internet, map production has progressed from producing hardcopy analog paper maps to maps with a multimedia format.

Unit 1. Data Considerations

Source material for cartographic mapping and visualization can sometimes be different than those used for general GIS. It is more directly linked to production scales. Certain types of cartographic maps have standard scales and standard map projections. Therefore, source material for map compilation, data abstraction, classification selection, and generalization could have special characteristics and requirements.

Unit 2. Principles of Map Design

The display of geographic data used in mapping and visualization has specific design principles. They include: page layout design, symbolization, use of color, and typography.

- Map design should first address the needs of special purpose maps, such as subdivision plans, cadastral mapping, drainage plans, nautical charts, aeronautical charts, geological maps, military maps, wire-mesh volume maps, and 3D plans of urban change. It should also consider how it is going to be viewed (e.g., distance, lighting, and media type) and by what audience (specialists or layperson). Design needs for a map to be viewed on the Internet are different than those of a 5- by 7-foot poster, and a geological map for geologists is designed differently from a general audience map.
- Symbolization can take different forms (e.g., visual, tactile, haptic, auditory, and dynamic displays). Visual variables (e.g., size, lightness, shape, and hue) and graphic primitives (points, lines, and areas) are commonly used in maps to represent various geographic features at all attribute measurement levels (nominal, ordinal, interval, and ratio). Single geographic features can be represented by various graphic primitives (e.g., land surface as a set of elevation points, as contour lines, as hypsometric layers or tints, and as a hillshaded surface).
- Selection of colors is a function of the theme, the variable, the purpose of the map, and the culture of the intended audience. In many cases real-world

connotations (e.g., blue = water, white = snow) are used to determine color selections on maps.
- Typography encompasses standard naming, labeling, label placement, type set fonts, size, style, and color. The position and properties of a label can facilitate better visual perception and interpretation of the map content.

Unit 3. Graphic Representation Techniques

Specialized mapping and visualization instances, such as thematic mapping, dynamic and interactive mapping, web mapping, and mapping and visualization in virtual and immersive environments, may require different, often specialized, representation techniques. Variations of graphic representation techniques include the following.
- Thematic maps, for instance, can be created using choropleth, dasymetric, proportioned or graduated symbolism, isoline, dot, cartogram, and flow map techniques. Each of these techniques has strengths and limitations in representing specific spatial phenomenon. Each has distinctive design considerations. Thematic maps can display a single or several variables with different mapping methods.
- Spatial phenomenon can be displayed dynamically and interactively. An example of a dynamic and interactive map is an on-line map of real-time information presented by animation. Temporal geographic data is one example that is well served by dynamic and interactive visualization.
- Methods for terrain representation include shaded relief, contours, hypsometric tints, block diagrams, and profiles. The representation terrain can be in 3D and 2 ½ dimensional representations.
- Web mapping considerations are the design of the user interface and the ability of the user to appropriately see the symbology and labeling. Web mapping can also serve as a method for posting and downloading data.
- Graphic representation is not limited to geographic phenomenon but can be used to illustrate the relationship among ideas. This is called spatialization and it is a core component of visual analytics.
- Uncertainty in the value of each of the components of data quality (positional and attribute accuracy, logical consistency, and completeness) can be represented visually as well. Graphic techniques can show different forms of inexactness (e.g., existence uncertainty, boundary location uncertainty, attribute ambiguity, and transitional boundary) of a given feature (e.g., a culture region).

Unit 4. Map Production

Map production on hardcopy media or on a digital media requires knowledge on output formats and printing (reproduction) methods. Maps can be reproduced in black and white or color, in high resolution (expensive prints or very large files) or low reproduction. Preservation of the original color scheme is a critical issue.
- Map production on a digital media can be in different output formats for raster maps (JPEG, GIF, TIFF) and vectors (PDF, Adobe Illustrator Postscript).
- Map production on a hardcopy media can be done with different printing devices or with lithographic offset printing. Reproduction parameters include: paper, ink, lpi (lines per inch), proof needs, press check, and other contract decisions.

Unit 5. Map Use and Analysis

Map reading is the translation of the graphic or other representation of features into a mental image of the environment. It involves the identification of map symbols and the interpretation of the symbology to understand the geographic phenomena. Maps can be understood easier if the shape and the color of the features on the map match corresponding features in the world.

Map analysis allows the reader to analyze and understand the spatial structure of and relationships among features on a map. Maps are used to find direction, distance, or position, plan routes, calculate area or volume, select facility location, or analyze the terrain (e.g., elevation determination, surface profiles, slope, viewsheds, and gradient). Maps can also be used to analyze spatial patterns of selected point, line, and area feature arrangements on maps.

Unit 6. Map Evaluation

Map evaluation standards for maps are similar to those used for traditional and GIS maps. However, because the objective of a map is to communicate a specific theme, the map should always be evaluated for its effectiveness for the intended audience.

Knowledge Area: Legal and Ethical Aspects of GIS

Legal regimes determine who can claim the exclusive right to hold and use geospatial data, the conditions under which others may have access to the data, and what subsequent uses are permitted. Ethical issues may also arise in all phases and facets of GIS.

Unit 1. Legal Aspects

When geospatial information is used for land management, among other activities, geospatial professionals may be liable for harm that results from flawed data or the misuse of data. Understanding the precepts of contract law and what liability standards entail is thus essential to mitigating risks associated with the provision of geospatial information products and services. The protection of personal private information that is present in many GIS systems (e.g., Census data and land record data) is also critical.

Unit 2. Geospatial Information as Property

Intellectual property rights include copyright, patents, trademarks, business methods, and other rights. These rights should apply to creators/owners of geospatial information as well. However, the nature and characteristics of geospatial information makes it difficult to establish and enforce the type of exclusive control associated with other proprietary information. This notwithstanding it is important to know what these rights are and how they can be enforced or defended against claims of infringement.

Unit 3. Dissemination of Geospatial Information

Geospatial data are abundant, but access to data varies with the nature of the data, who wishes to acquire it and for what purpose, under what conditions, and at what price. Legal relations between public and private organizations and individuals govern data access. Legal mechanisms for sharing geospatial information include contracts and licensing agreements. Legal issues can also arise from the necessary balance between desire for open access and security constraints.

Unit 4. Ethical Aspects of Geospatial Information and Technology

Ethics provide frameworks that help individuals and organizations make decisions when confronted with choices that have moral implications. Most professional organizations develop codes of ethics to help their members "do the right thing", preserve their good reputation in the community, and help their members develop as a community. Examples of GIS-related professional codes of ethics are those developed by the GIS Certification Institute (GISCI) and ASPRS.

Unit 5. Critical Thinking about GIS

A monumental challenge is to think critically about GIS from a wide range of perspectives. It includes questioning the assumptions about the purported benefits of GIS and paying attention to its unexamined risks. Understanding the range of critical perspectives of GIS will increase the likelihood that it will fulfill its potential to benefit all stakeholders.

Knowledge Area: Management and Organization Aspects

This knowledge area addresses the management of GIS—including hardware, software, data, and workforce—in private and public organizations. Knowledge in allied fields such as economics, business, and business administration is assumed for mastering this knowledge area. Also considered are local, national, and international organizations concerned with the coordination and effectiveness of GIS.

Unit 1. Management Aspects

The prerequisites for managing GIS operations and infrastructure entails the understanding of the nature of the organization, its activities and GIS needs, and applying approaches and models to get it done. A GIS operations manager will be responsible for developing realistic schedules, calculating budgets, allocating competent workforce, establishing operational procedures (e.g., data access, revisions, quality assurance/quality control (QA/QC), and periodic system assessments). Some managers will also need to be involved hands-on in gaining political support from decision makers as well as users.

Unit 2. Economic Aspects

Most organizations insist that investments in GIS be justified in economic terms. This includes the somewhat tall task of quantifying the value of information, and of information systems as a whole. It also includes cost/benefit analysis for a process where the quantification of benefits is much more difficult than the quantification of costs.

Unit 3. Organizational Structures and Procedures

GIS implementation and use within an organization often involves a variety of participants, stakeholders, users, and applications. Organizational structures and procedures address methods for developing, managing, and coordinating these multipurpose, multiuser GISs and programs.

Unit 4. GIS Workforce

Incorporating GIS in an organization's workflow often requires greater attention to standardization and can lead to resistance to change. These issues can be met heads-on by encouraging staff development through GIS training and education. Part of this is to overcome resistance to change and the need to standardize operations when trying to incorporate GIS.

Unit 5. Institutional and Inter-institutional Aspects

As GIS creation and use extends beyond the traditional in-house data warehouses and web services (within one organization), the fuzzy boundary between formal and informal organizations and interinstitutional use will have societal and ethical implications within and beyond each organization. This can be facilitated by adopting industry-wide standards that enable data sharing and technology transfer. Open access to (and sharing of) geospatial information has to be balanced against security and privacy constraints. Consequently, one should evaluate the advantages and disadvantages to an organization when using GIS portal information from other organizations or entities (private, public, nonprofit).

Unit 6. Coordinating Organizations (National and International)

A number of public, private and non-profit organizations exist to coordinate, inform, and support geospatial activities of professionals and entities using GIS. Informed geospatial professionals and organizations are familiar with the mission, history, constituencies, modes of operation, products, and levels of success of these organizations. Knowledge of the various federal, state, professional, industrial, academic and other organizations that impact the geospatial profession and their mission is critical for effective involvement in GIS.

Categorizing the GIS Body of Knowledge for Surveying

The just outlined surveying GIS body of knowledge covers an extensive range of topics and issues. No individual human being is capable (nor is it necessary of him/her) to master this entire body of knowledge. The degree of the depth and breadth of the required knowledge is a function of the role and the level of involvement that the individual surveyor assumes in GIS. An extensive GIS application may require more elaborate knowledge compared with that required of a casual GIS usage. Marble (1998) suggests six roles played by GIS&T professionals. The six levels (from the least intensive knowledge requirements to the most) are:

- Basic spatial and computer understanding
- Routine use of basic GIS technology
- Higher level modeling application
- GIS application design and development
- GIS system design
- GIS research and software development

Each of these roles requires familiarization with different knowledge areas, but even in a specific knowledge area the required depth or breadth may vary as a function of a specific undertaken role.

To determine what parts of the surveying GIS body of knowledge are mandatory to all surveyors and which parts are required only for some, it is crucial to define the roles surveyors may assume in GIS. If the role is the routine use of basic GIS technology, then most of the knowledge included in areas such as analytical methods would not be mandatory because that knowledge is geared for advanced in-depth analysis of spatial data. However, if a surveyor elects to become engaged in research and software development, the knowledge in the analytical methods area would be definitely required. In both cases, basic core GIS knowledge such as parts of the geospatial data knowledge area should be required of every surveyor. Figure 2 shows some of the diverse roles that surveyors may undertake in GIS beyond the role of GIS technology user. Some of these roles are professional specializations or expertise while others are utterly scholarly roles.

Based on the above observations that surveyors are involved in GIS at various levels of intensity, it is prudent to define the required GIS knowledge as a function of the level of involvement. In this chapter three breadth and depth knowledge categories are defined. The knowledge categories are:

Category	Knowledge Level
Basic	breadth of knowledge that everyone in the surveying profession should have
Specialization/expertise	a depth knowledge with ability to perform with confidence
Scholarly	levels of knowledge with ability of research and development to lead the profession to its future challenges

The three categories represent a minimal, an intermediate, and an advanced level of GIS knowledge. The minimal level of GIS knowledge a surveyor must master should enable him/her to routinely use basic GIS technology. This includes not only the ability to retrieve and display spatial data but the ability to perform data manipulations (data conflation, projections, etc.) and the ability to deliver surveying findings to their clients in a GIS format. The next level of the surveyors' role in GIS is termed as GIS specialist or expert. A GIS specialist in this context is a surveyor whose main professional practice focus is in GIS. This would normally entail developing and maintaining GIS applications on a regular basis. A surveyor who is a GIS specialist is a professional who is able to perform the entire design and implementation processes from start to finish and understand the context in which and for which that GIS system exists. Other duties performed by a GIS specialist could include maintenance of enterprise GIS systems, adaptation of new technologies, and migration of geospatial systems to new conceptual models, for example, migration from a relational database concept to object oriented database concepts.

The highest level of a surveyors' role in GIS is termed a GIS scholar. GIS scholars are surveyors whose main professional objective is to develop solutions for surveying (or surveying related) problems with GIS concepts, for example, reconciling deed conflicts to create a seamless parcel layer or create a dynamic GIS application for points affected by crustal motion. A surveying scholar can also incorporate surveying concepts and solutions to solve GIS problems, for example, the entire domain of uncertainties errors are well suited to be handled by a surveying scholar. The role of the GIS scholar should place the surveying profession in the forefront of GIScience research and development. There is no reason why individuals with surveying expertise should not be involved in shaping the future of GIS knowledge and technology.

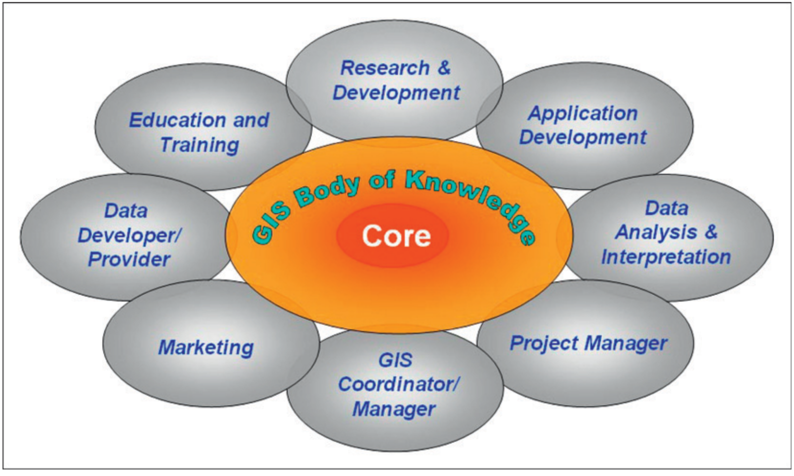

Figure 2. Some roles of surveyors in GIS.

Levels of Competency

The basic, specialist, and scholar competency categories will require not only different breaths of GIS knowledge but also different depths of knowledge. Greenfeld and Potts (2008) suggested three levels of knowledge and competence depths that were used for the macro level surveying body of knowledge. The three levels of competence are:

- Level 1 (Recognition) represents a reasonable level of familiarity with a concept. At this level, the surveyor is familiar with a concept, but lacks the knowledge to specify and procure solutions without additional expertise. For example, a surveyor might recognize that a particular GIS

GIS Knowledge	Basic	Specialist	Scholar
Area: Conceptual Foundations			
1. Philosophical and social perspective	U	U	A
2. Domains of geographic information	U	U	R
3. Elements of geographic information	A	A	A
4. Geospatial relationships	U	A	A
5. Imperfections in geographic information	U	A	A
6. The origin/history of GIS	U	U	A
Area: Data Modeling			
1. Basic storage and retrieval structure	A	A	A
2. Database management systems	U	A	A
3. Tessellation data models (e.g., raster data model)	R	U	A
4. Vector and object data models	A	A	A
5. 3D, temporal and uncertain phenomena data models	R	U	A
Area: Design Aspects			
1. The scope of GIS system design	U	A	A
2. Project definition	R	A	A
3. Resource planning	R	A	A
4. Database design	R	A	A
5. Analysis design		A	A
6. Application design		A	A
7. System implementation		A	A
Area: Geospatial Data			
1. Earth geometry	A	A	A
2. Georeferencing systems	A	A	A
3. Datums	A	A	A
4. Map projections	A	A	A
5. Land partitioning systems	A	A	A
6. Data quality	A	A	A
7. Spatial data compilation	A	A	A
8. Field data collection	A	A	A
9. Metadata, standards, and infrastructures	U	A	A
Area: Data Manipulation			
1. Representation transformation	A	A	A
2. Generalization and aggregation	U	U	A
3. Change management of geospatial data	R	A	U
Area: Analytical Methods			
1. Query operations and query languages	U	A	A
2. Geometric measures	A	A	A
3. Basic analytical operations	A	A	A
4. Basic analytical methods	U	A	A
5. Analysis of surfaces	A	A	A

R = recognition; U = understanding; A = ability.

Table 2. The surveying GIS knowledge areas and topics and a suggested level of competencies.

Table 2. *(Continued).*

GIS Knowledge	Basic	Specialist	Scholar
Area: Analytical Methods			
6. Spatial statistics	R	U	A
7. Geostatistics		R	A
8. Geocomputation		R	A
9. Data mining		R	A
10. Network analysis		U	A
Area: Cartography and Visualization			
1. Data considerations	U	A	A
2. Principles of map design	A	A	A
3. Graphic representation techniques	U	A	A
4. Map production	U	A	U
5. Map use and analysis	U	A	A
6. Map evaluation	U	A	A
Area: Legal and Ethical Aspects of GIS			
1. Legal aspects	A	A	U
2. Geospatial information as property	A	A	U
3. Dissemination of geospatial information	R	A	R
4. Ethical aspects of geospatial information and technology	U	A	U
5. Critical thinking about GIS		U	A
Area: Management and Organization Aspects			
1. Managing aspects	R	A	
2. Economic aspects	R	A	
3. Organizational structures and procedures	R	A	R
4. GIS workforce	R	A	
5. Institutional and inter-institutional aspects		U	
6. Coordinating organizations (national and international)		U	

project poses significant implementation challenges without having the expertise to devise improved implementation or design alternatives.

- Level 2 (Understanding) implies a thorough mental grasp and comprehension of a concept or topic. Understanding typically requires more than abstract knowledge. For example, a surveyor with an understanding of boundary law should be able to identify and to communicate legal issues arising from a practical case study.
- Level 3 (Ability) is a capability to perform with competence.

Table 2 shows the surveying GIS knowledge matrix. It shows the previously described knowledge areas and topics and provides a suggested level of competency for each involvement category. The required level of competency under the basic role of surveyors in GIS is relatively straightforward. It is anticipated that every surveyor acquires this basic knowledge. However, the required competencies under the roles of specialist and scholar surveyors are more complex. Not every specialist and every scholar has to master the entire suggested competencies in all knowledge areas. But, a specialist or scholar should have a higher competency in their specific area of specialization than does a surveyor involved in basic GIS operations. For example, a cartography specialist has to master, at an ability level, all the topics listed under the cartography and visualization knowledge area. The same specialist may not necessarily need the specialist competencies in another knowledge area such as analytical methods. It is reasonable to assume that basic competencies in the area of analytical methods will suffice for a cartography and visualization specialist, for instance.

	Undergraduate Degree	Professional Education	Post Baccalaureate Certification	Graduate Degree
Basic user	R	R	P	—
Specialist	R	R	R	P
Scholar	R	P	P	R

R = required education; P(+) = additional education preferred.

Table 3. GIS educational requirements for surveyors.

GIS Education for Surveyors

One persistent challenge for the surveying profession in the U.S. is the lack of mandatory college education for licensure across the nation. Experience gained under a licensed surveyor for any length of time will not enable the surveyor to acquire the minimum GIS body of knowledge as outlined above. It is reasonable to expect that curriculums in all 4-year degree surveying programs will enable their graduates to become, at least, a competent routine user of GIS. Graduates from a typical surveying program who take additional GIS classes or graduates from surveying programs with GIS concentration could become GIS specialists. To become a GIS scholar one would need an advanced degree, preferably (but not necessarily) in surveying/geomatics or in another related discipline. One can also become a GIS scholar with surveying specialization by earning a related or unrelated undergraduate degree (e.g., in science, math, or in engineering) and an advanced degree in surveying/geomatics. The educational requirements for the three roles of surveyors in GIS are shown in Table 3.

Summary

The GIS body of knowledge for surveying is defined as a subset of the broad definition of the entire Geographic Information Science and Technology body of knowledge. Because surveyors may focus their professional practice on different aspects of surveying (not necessarily in GIS), the body of knowledge is categorized according to the level of involvement or the role a surveyor elects to have in GIS. Three levels of involvement and corresponding competencies were defined. The first is a routine use and application of GIS, the second is GIS specialist, and the third role is GIS scholar. For each of these roles, the body of knowledge, the level of competencies, and the educational requirements were described in this paper.

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Surveying Body of Knowledge for Positioning

Joseph Paiva

Introduction

Surveying is a diverse profession covering wide-ranging technical, logistical, and professional activities. Some of those activities include, but are not limited to:

- Business practices relating to defining the engagement and defining the scope of work and responsibilities of the parties;
- Conducting research, assessing the results of that research, and planning the work;
- Managing field and office teams;
- Data collection and quality assurance;
- Data processing;
- Data analysis and assessment of results;
- Data interpretation;
- Drafting, computer aided drafting (CAD), and other activities related to reporting and publishing the work results;
- Computer programming;
- Various science disciplines;
- Professional ethics;
- Policy development;
- Teaching and research; and
- Running a business.

In addition to various levels of possible application, surveying also includes numerous specialties such as land (property boundary or cadastral) surveying, construction surveying, engineering surveying, photogrammetric surveying, control surveying, hydrographic surveying, mining surveying, forensic surveying, and others. Persons who call themselves surveyors may perform activities ranging from property surveys to construction layout, to making topographic maps, to making an inventory of and locating utilities or "as-built" records, to managing the collection, processing, manipulation, storage, display, and interpretation of spatial data. It is indeed a challenge to list, much less understand, the complete range of activities included in this profession called surveying. But, in one form or another, most surveying activities involve the collection, management, and representation of spatial data founded on positioning.

Surveying is one of several disciplines that work with spatial data but unlike the others, the surveying profession has an innate responsibility for relating spatial data to boundary lines and land ownership. This particular responsibility gives the surveyor a unique niche in the range of services provided to society, and any statement of a Surveying Body of Knowledge (SBOK) should focus first on that scope of knowledge. However, the knowledge needed to relate spatial data to ownership and boundaries does not stop with knowing and understanding laws related to land ownership. The successful modern surveyor also needs to be able to perform tasks (skills) based upon an understanding of principles (knowledge) in other areas.

Fundamental Concepts of Positioning

Consistent with the International Federation of Surveyors (FIG) definition of the functions of a surveyor, positioning is an umbrella term for "use of geospatial data for determining and describing the location, movement, or both, of or between objects anywhere within those parts on, below, and above the Earth where the interests and activities of humans occur." It should be noted that surveying activities might also be conducted outside the envelope of the Earth as human endeavor has reached out into space and other planets or celestial bodies. A first-level breakdown of positioning knowledge areas is as follows:

- Measurements (with respect to the aspects of technology and processes) of physical quantities in various combinations, such as, but not limited to, distances, angles, time, temperature, signals, current, pressures, and mass.
- Physical laws that govern how measured quantities are reduced to their geometrical and temporal components.
- Solid geometry and other mathematical tools used to describe the spatial relationships of points, lines, surfaces, and objects in the context of coordinate systems and datums.

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- Computer tools (both hardware and software) used to manipulate three-dimensional (3D) digital spatial data.
- Error estimation, error propagation, least squares adjustment, and other tools required to determine, monitor, and evaluate spatial data accuracy.
- Standards and specifications used throughout the spatial data user community for evaluating, assessing, and categorizing spatial data to determine suitability for given applications.
- Information management as related to establishing and preserving the value of spatial data.
- Communication principles within the context of personal and business relationships as well as professional interactions within a discipline and between disciplines.
- Economic, business, and legal (*sans* boundary) concepts as related to successful participation in a successful organization or enterprise.

While fundamental concepts remain relevant and essential, it is also recognized that context (in terms of the wide range of surveying activities) plays an important role in relating requisite knowledge to skills and outcomes. Currently many surveying operations, calculations, and analyses are performed in two dimensions, with orthometric heights or other heights added as a one-dimensional supplement. However, as a result of the digital revolution of the past 50 years, spatial data are now characterized as digital and 3D. The associated paradigm shift from analog to digital forces a return-to-basics, but it also has implications for everyone who uses spatial data, especially those in the surveying profession. A forward-looking description of both local and global applications based on the assumption of a single origin for 3D data is given in a treatise by Burkholder (2008).

The SBOK needs to accommodate, and it is likely that the surveying profession will adopt, a comprehensive true 3D data model. This paper attempts to address conventional positioning methods as well as what is likely to become common practice with respect to this more highly integrated way of handling spatial data.

Specifics and Applications

For the fundamental concepts given in the previous section to have a practical meaning, the associated operational skills need to be included in the discussion. It should also be noted that the practical implementation of these concepts will yield applications that are dynamic and subject to change.

The principal knowledge areas for positioning are:

- Measurements;
- Data analysis and management;
- Adjustments;
- Coordinate geometry; and
- Information extraction.

These knowledge areas and their relevance to positioning are discussed in the subsections below. The order in which these areas have been listed does not indicate their relative importance.

Knowledge Area: Measurements

When performing positioning activities—often referred to as the fieldwork phase of the surveying process—it should be understood that while many measurement technologies may require only minimal human presence in the field, others cannot be applied without working in the field. This notwithstanding, evaluation of the variables that affect the measurement process is an integral part of this knowledge area, as is consideration of the various tools that can be used to accomplish the objectives and align the work, technology and human resources to time and budget constraints. The quality of positioning desired so that the best possible design of the survey can be developed is another important part of the measurements knowledge area.

1. Core Unit: Situational Analysis

To perform measurements well, especially with modern technologies that are highly automated (but programmed to use an elaborate list of setup variables that can be dynamic based on feedback from sensors and the measuring system itself), it becomes even more important to understand the situation in which these technologies will be applied. Understanding the design and operational criteria that were applied and are supported by the technologies is vital for obtaining reliable, quality measurements with the particular application for which the measurements are made. Situational analysis includes the following:

- Geometries;
- Terrain;
- Field conditions;
- Principles of reconnaissance; and
- Application and development of cost and time budgets.

2. Core Unit: Technology and Measurement Regimen Selection

The process of positioning involves the application of technology in a specific, intentional manner so as to obtain that quality of the appropriate measurements required to accomplish the task. To select the optimum technology and measurement regimen, we need to understand how the technology choices we make in a particular situation help to accomplish the project's objectives with the available resource on schedule, and within budget. Survey pre-design and pre-analysis may be part of this core unit; error analysis (usually post-survey) is described below. An optimal combination of technology and measurement will take into account:

- The number and types of positioning devices available to select from;
- General procedures to be followed;
- Peripheral devices most appropriate for use with the primary technology(ies);
- Competency of the personnel involved in making the measurements and provisions made for training;
- and, if included in the project design:
  - Survey predesign for efficiency; and
  - Survey preanalysis for ensuring that survey requirements are met.

3. Core Unit: Systematic Error Analysis

In order to ensure quality measurements, it is imperative that an analysis of the systematic error introduced during the measurement process be conducted. Evaluation of the magnitudes of the errors and determining which ones should be compensated, as well as the method(s) by which they will be compensated, is a part of this core unit. Many options for accounting and compensating for systematic error exist, including observation of measuring conditions and using models after the fact, using built-in mechanical or software functions in the instrumentation, or following specific procedures which eliminate or reduce systematic error. Sometimes, a combination of these methods may be used. Other topics in this core unit include a thorough understanding of the design concepts used in the technologies that are to be applied in the project, identifying ways in which blunders can be introduced into the measurement process, introducing procedures that minimize them, and understanding how ambiguities in measurements or calculated results may occur so as to identify the most appropriate ways to reduce them. Methods for removing or detecting systematic errors may include introduction of independent or redundant measurements. A brief list of topics within this core unit includes:

- Identification of systematic error sources and categorizing them (natural, instrumental, personal);
- Identification of how the systematic error sources will be compensated (field procedures, instrumental compensation systems, instrumentation firmware, postmeasurement phase processing);
- Understanding, elaboration, or development of models for systematic error compensation, including integrating sensor design consideration into the processes;
- Blunder elimination and detection processes including graphical, computational, and statistical methods; and
- Development of measurement techniques that use independent measurements to improve survey system quality.

4. Core Unit: Application of Mathematical Models for Data and Information Representation

This core unit focuses on understanding project requirements for display and the use of information from the field survey and subsequent analysis, manipulation, and representation processes. Topics include development of specifications and processes for measurements and the subsequent representation using such mathematical constructs as coordinate systems and projections. To build mathematical models, one needs to have a thorough understanding of datums and regional spatial data representation systems, transformations of data, and the use of advanced geospatial data models in a way that supports geospatial professionals, including surveyors, as well as consumers of the data and information developed. Ellipsoids, adjustments, and velocity of control may be additional topics in this core unit. Representative topics include:

- Ellipsoids, datums, and other 1 to n dimensional surfaces of representation;
- Projections;
- Three-dimensional data models;
- Control networks, establishment, and use including adjustments and velocities; and
- Spatial data transformations between different datums, projections, data models (2 + 1

dimensions to 3 dimensions and *vice versa*), height systems, and coordinate systems.

5. Core Unit: Designing or Applying Survey Control

Consistent with project requirements, an investigation of existing control must be done to determine its appropriateness. Such investigation may involve fieldwork and measurements to verify the integrity of control. Specifications must be developed for the measurements to ensure that the control is used in a way that will yield the quality of data required for the project. Topics may include:

- Design and implementation of design to create a control network;
- Existing control research including field investigation and evaluation; and
- Determination of usability (topography, obstacles, and proximity limitation analysis) of found control.

6. Core Unit: Field Survey

Field surveys encompass all the activities done in the field using designated technologies, equipment, and procedures. They may include collection of data from third parties (for example, records from various offices, fellow practitioners, collaborators executing part of the measurement scheme, and sources not originally intended for use in the project but which are determined by the professionals to be useful), passive measurement, and monitoring systems. Data examination for integrity and quality (including detection and elimination of blunders) are also part of this knowledge unit. A normal and legitimate part of this area may be a secondary field activity to resolve ambiguities or to improve quality of measurements. Thus, this core unit may include:

- Integrated data collection schemes that reflect all sensors used in a project or scheme;
- Collection, inspection, and use of data from third parties;
- Design of monitoring systems;
- Use of data from monitoring systems;
- Data inspection for blunders and integrity, completeness, and quality; and
- Decision systems for secondary field activities to resolve ambiguities or amend level of quality or completeness thus far obtained.

Knowledge Area: Data Analysis and Management

While the activities performed in this knowledge area are often considered to be post fieldwork, it should be recognized that there is an active human-, and sometimes technology-based process of data analysis and management that occurs during the measurements phase, such as evaluating and adjusting the methodologies and processes that may have been designed. There is an aspect of data management, especially when several sensor technologies are used, which increases the complexity of the work. This is due to the fact that in most projects more than one positioning technology must be used to accomplish the project's goals, or even a specific task or sub-task.

1. Core Unit: Examination of Data for Completeness

When data have been organized in a systematic fashion, they should be examined for completeness. This may include examination of the quality of the data, and not mere verification that the required measurement has been made. It may also include blunder detection, a topic common to many knowledge areas and core units. Examination of data completeness typically includes:

- Data verification and organization for processing;
- Data quality checks against project specifications;
- Checks for data homogeneity across sensor types; and
- Blunder detection.

2. Core Unit: Postprocessing for Systematic and Random Error Evaluation and Reduction

"Post-processing" is used here to represent all types of computations and analysis irrespective of whether they are done by estimation, hand calculation, calculator, computer software, or some other means including graphical methods. Error reduction and/or removal is an integral part of the measurement process. Measurement systems may have built-in error reduction components, either in the field procedures or through adjustments to the process aimed at ensuring a more accurate solution. Some of these include mechanical (e.g., by physically positioning an electronic distance measurement (EDM) retroprism to compensate for its optical offset); preprogrammed electronic, mechanical, or software offsets (e.g., Global Navigation Satellite Systems antenna phase center error compensation); or a combination of detection (e.g., electronic measurement of atmospheric pressure by the total station), computation of an error (determining shortening or lengthening effect of the atmospheric pressure on the EDM measurement), and application of the correction so that the displayed or stored value requires no further correction for this error source (software manipulation of the raw measurement to represent a corrected value). Evaluation of preprogrammed or preset correction methodologies for accuracy is a significant part of the error reduction process.

As random errors are always present in the measurement process, this core unit also includes mathematical, scientific, and analytical processes for determining the probabilities and magnitudes of random errors across the measurement processes. Included in this core unit are:

- Organization of systematic errors by origination point in the process;
- Evaluation of magnitude of each systematic error;
- Determination of whether systematic error components are significant for inclusion in data adjustment;
- Evaluation of sufficiency of built-in correction methodologies;
- Estimation of *a priori* random errors;
- Evaluation of *a posteriori* random errors;
- Development and application of a model for random error adjustment; and
- Development of estimates of uncertainty in measured quantities due to random error.

3. Core Unit: Analyze Data for Precision and Accuracy

The precision of measurements can be determined through an analysis of redundant measurements and their frequency of occurrence. Then, after making sure that systematic error has been corrected, statements can be made about the survey's accuracy. This core unit also includes inspection of the survey processes to determine if they are in compliance with the accuracy standards that the survey must meet. This core unit comprises the following knowledge topics:

- Evaluation of precision of the measurements;
- Use of error propagation of observation components to develop a statement of measurement accuracy;
- Evaluation of completeness of systematic error correction in context of specifications or other project requirements;
- Evaluation of internal and external reliabilities of the measurements;
- Reaching of conclusions about project accuracy;
- Quality control/quality assurance evaluation of project results with specifications; and
- Use of statistical hypothesis tests for acceptance or rejection of results.

4. Core Unit: Determine if Additional Measurements are Required

Additional measurements may be required to ensure that the survey is complete and conducted to the prescribed level of accuracy. Such measurements may be done to replace measurements of suspect or clearly low quality or to augment initially conducted measurements, or to strengthen the survey network needs with measurements whose methodology yields the desired level of accuracy. Among this unit's knowledge topics are:

- Evaluation of data to determine sufficiency with respect to project specifications;
- Evaluation of project data to evaluate sufficiency with respect to projected uses of the data; and
- Determination of remedial measures to correct project or subproject deficiencies or inadequacies.

5. Core Unit: Integrate Data from Various Sensors into a Homogenous Database

As measurement systems vary considerably with respect to the core technology(ies) that they may include, the measurement data need to be organized in such a way so that they can be combined in a homogenous database. This knowledge area is particularly relevant to surveyors as the variety of tools they use is bound to increase, as are the types of measurements that they make. Much of the data integration is relatively simple, revolving around making corrections for technology-introduced systematic and developing random error estimates for each set of measurements acquired with a given technology. Then reduce them to a common basis, such as vectors, coordinates, or scalars applied to vectors.

A significant aspect of this core unit is the determination, management, attachment, and publication of metadata related to the survey process and all subsequent processes applied to the raw measurements so that future uses and users of the data are fully cognizant of the conditions under which this data has been created and published. The primary topics within this core unit are:

- Development of tools and strategies for integration of data from various sources and sensors;
- Application of selected data integration methodologies;
- Evaluation of mathematical and spatial reference framework modeling necessary for integration of data from various sources and sensors; and
- Development and attachment of complete meta datasets to the data.

Knowledge Area: Adjustments

This knowledge area covers a variety of processes that are used to interpret the information generated from the measurement data and their analysis. Specifically, it covers techniques that use the mathematical principles of probability and statistics to adjust the data for internal consistency. Adjusted measurements are then propagated across external control or frameworks to determine whether further adjustments are needed. Sometimes the result of this analysis is to return to the data analysis at the management stage.

1. Core Unit: Apply Different Adjustment Procedures for Data Processing

Different adjustment methods can be used to process measurements. Examples are the conceptual adjustment method, the mathematical model of the adjusted network, the weighting scheme, and the evaluation/assessment instruments generated by the adjustment process. The application of this knowledge is intended to create the most appropriate unbiased solution for given measurements and process them in a comprehensive systematic approach. The primary topics are:

- The adjustment approach for processing the measurements using the least squares criteria including observation equations, condition equations, constraining equations, and a combination of the above;
- Understating the formulation of the mathematical of relationships among measurements from various sources in an adjustment process;
- Stochastic modeling of the measurements for weighting purposes; and
- Determination of quality assessment instruments to be generated by the adjustment process.

2. Core Unit: Apply Statistical and Adjustment Tools to Improve Quality of Information Being Reported

Here the information generated in the data analysis stage is supplemented, where necessary, with statistical and probability data to provide adjusted information about the survey. This largely internal consistency process ensures that the survey has been conducted to the accuracy level determined before the survey was begun. Topics include:

- Application of graphical quality assessment tools including histograms, scatter plots, and error ellipses;
- Application of statistical confidence interval and statistical hypothesis tests for quality assessment including the meaning of these findings; and
- Application of statistical tests for detection and elimination of marginally small blunders.

3. Core Unit: Calculate Integrity of Networks and Other Geometries

Whether the purpose of the survey is to densify an existing network with comparable accuracies or to establish a new network at a lower accuracy level, the survey must fit within the already existing framework, or, if it doesn't, reasons must be given for why an inconsistency is permissible. This analysis of the survey may involve examination of the horizontal and vertical components, as well as the dynamics that cause movement of control over time. The primary topics are:

- Understanding of the dynamic nature of local and global ground/crustal movement; and
- Modeling of the dynamic movement using time series and other mathematical methods.

4. Core Unit: Apply Principles of Geodesy

Depending on the extent of the survey and its purpose, principles of geodesy may have to be introduced to define the surveyed points, lines, planes, and volumes in other datums and projections. This core unit can include elements that involve estimation of relationships between datums applicable to the survey. Where there is no explicit defined relationship, additional field measurements could be conducted. Topics include:

- Understanding natural, celestial, and terrestrial coordinate frameworks;
- Understanding how an irregular surface (e.g., the earth) can be represented mathematically,

including representation on an ellipsoid (in 3D or with geographic coordinates) and on a plane (projection into plane coordinates);
- Understanding the impact of the curved surface of the earth and atmospheric conditions on measurements including physical (e.g., refraction) and geometrical reduction of measurements between points separated by a long distance;
- The impact of gravity on angular and distance measurements including the deflection of the vertical;
- Definitions of gravity and geometry-based height systems;
- Understanding the nature of earth dynamic motion and movement; and
- Modeling of the dynamic movement using time series and other mathematical methods.

Knowledge Area: Coordinate Geometry

Coordinate geometry is a knowledge area that covers all of the planar and spherical considerations in calculating positions, lines, planes, and volumes in a variety of data and projections.

1. Core Unit: Apply 2D and 3D Transformations

In this core unit, transformations are applied to convert information represented in one coordinate system into one or more other systems. Such transformations may include translations, rotations, scaling, and additional conversions with respect to height (or elevation) and other coordinates, as well as the units in which these are expressed. The primary topics covered by this unit are:
- Mathematical definition of coordinate transformation and the parameters used to perform the transformation; and
- Modeling of differences between coordinate systems in terms of dimensions, geometric integrity, and projection foci to enable consistent transformation.

2. Core Unit: Determine Projected Coordinates

When the starting information or an entire survey is to be represented in another system, projecting or reprojecting positions into a plane system of representation may be required. This core unit deals with concepts of developable surfaces and the mathematics for representing plane coordinates in one surface and, if necessary, transforming them into another. This may or may not involve changes in datums and ellipsoids. The primary topics are:
- The extrinsic definition of projecting curvilinear coordinates into a plane including the nature of projections (plane, conical, cylindrical), coincidence (tangent, secant, etc.), position (normal, transverse, oblique), etc.;
- The characteristics of map projections including properties (e.g., conformal, equidistant, equal area) geometric projections, least squares-based minimal distortion projection, and others; and
- Distortion quantification of map projection.

3. Core Unit: Determine Geodetic Coordinates

When surveys are performed, the raw observations and representations of control may need to be represented on an ellipsoid and an associated geoid. This core unit involves the science and mathematics of making the reductions from a plane surface or surfaces to an ellipsoid and geoid or the conversion of a system of coordinates from one ellipsoid and geoid to another set.

4. Core Unit: Determine Positions of Surveyed Points

When a survey is being done to collect data about the existing surface (including any structures and modified natural surfaces), the raw measurements, regardless of system and technology used to make them, must be analyzed, corrected, adjusted, and reduced as covered in previous units. They must then be related to the control on the particular target system selected for final representation of the survey. This core knowledge area covers the mathematical processes and analysis that must be done to accomplish that representation.

5. Core Unit: Determine Position or Configuration of Designed Points, Lines, Surfaces, and Volumes

When points, lines, and other features that have been designed are to be laid out, it must be done in relation to a projection and datum ellipsoid. Often, these design positions may be calculated on a tangent plane, using mathematical processes to convert the data from the system in which they were designed to the target system. Analysis of the underlying metadata associated with each design feature is part of this knowledge area; such an analysis will enhance the understanding of the target system in which the points will be laid out. Topics are:

- The inverse process of measurement reduction that was necessary to process raw data;
- The diffusion of the natural form of the surface of the earth into the geometric definition of points and lines; and
- Assessment of the accuracy of the reprojected positions of points.

6. Core Unit: Determine Areas and Volumes

A key part of the results generated by surveys is to report on the quantities measured. More often than not these are coordinates, lengths, and slopes, but they may also include areas and volumes. Calculation of areas and volumes requires knowledge of solid geometry. Where necessary, processes used to represent datums and projections and to convert points, lines, areas, and volumes from one system to another may be required. The primary topics are:

- Understanding of the mathematics of solid geometry;
- Quantification of the differences between the representation of the surface of the earth and the actual form of that surface; and
- Assessment of the accuracy of areas and volumes.

Knowledge Area: Information Extraction

Seldom does only generating coordinates and a graphical representation create a survey result. This knowledge area covers the critical phase of converting data into information that consumers of this information, both surveyors and non-surveyors, can readily access and use. Interpretations, conclusions, and even advice are all part of information extraction.

1. Core Unit: Report Positions, Lines, Surfaces, and Volumes

The first core unit in this knowledge area covers the most basic of reporting of information obtained from a survey and any subsequent calculations. Such reporting may be accomplished through maps, charts, and tables, and the professional engaged in this work will need to be cognizant of the following knowledge areas:

- Report design, report writing, and communication skills;
- Map design;
- Adherence to required standards and specifications; and
- Proficiency in metadata standards and documentation.

2. Core Unit: Report Conclusions, Deductions, and Inductions

Data collection, analysis, and manipulation generates information that empowers users. Sometimes the expert knowledge of the surveyor is required to generate, for the next user in the chain of users, reports of conclusions, deductions, and inductions from the data. This is because surveying does not mean only making physical measurements; surveys often include other observations made by the surveyor that add layers of color and complexity to the data. Core unit topics include:

- Understanding of the complete output of the processing software;
- Ability to understand the relevancy of the results and the associated quality indicator(s) to the current project, and its (their) limitations; and
- Effective communication of the above findings to subsequent users.

3. Core Unit: Create Maps and Reports that are Project- and Consumer-Specific

When reports, map plats, or maps are generated from a survey, the surveyor may be required to focus on particular parts of the survey or report the data in such a way that the information desired by the client or the users is readily accessible. The primary knowledge areas in this unit are:

- Understanding of the context, the scope of the project, and the needs of client, for which the data were compiled;
- Map communication skills; and
- Adherence to required standards and specifications.

4. Core Unit: Use CAD/GIS to Generate User Products

The information and data products generated by surveyors may be represented in the form of a computer-aided drawing or some other design environment that may be deployed on a

GIS platform. The topics in this core knowledge area include:

- Understanding the process of creating a digital map or digital representation of the surface of the earth;
- Understanding the product delivery environment and tools;
- Understanding the advantages/disadvantages, capabilities/limitations of the delivery platform; and
- Familiarization with CAD/GIS or other standards and specification and adherence to them.

Education for Surveyors

As stated in the preface to the surveying body of knowledge, one persistent challenge facing the surveying profession in the United States is the lack of mandatory college education for licensure across the nation. Experience gained under a licensed surveyor for any length of time will not necessarily enable the surveyor to acquire the minimum positioning body of knowledge. It is reasonable to expect that curricula in all four-year-degree surveying programs will enable their graduates to become competent routine practitioners of the positioning body of knowledge, at the minimum. Graduates from a typical surveying program who take additional classes or graduate from surveying programs with concentrations in analysis, technology, and data modeling could become positioning specialists. To become a positioning scholar it is anticipated that an advanced degree would be required. The advanced degree would preferably (but not necessarily) be in surveying/geomatics or in another related discipline. One can also become a positioning scholar by earning a related undergraduate degree (e.g., science, mathematics, or engineering) and an advanced degree in surveying/geomatics that includes advanced positioning tracks. The educational requirements for the three roles of surveyors in basic, specialist, and scholar roles are shown in Table 1. *R* indicates that the education is required and *P* (plus) indicates that it is preferable to have that additional education.

Levels of Competencies and Knowledge Depth

Competency

Greenfeld et al. (2008) suggest a simplified three levels of knowledge and competence depth previously used for the macro level surveying body of knowledge. The three levels of competence are:

- Level 1 (Recognition – indicated with "R" in tables below) represents a reasonable level of familiarity with a concept. At this level, the surveyor is familiar with a concept, but lacks the knowledge to specify and procure solutions without additional expertise. For example, a surveyor might recognize that a particular GIS project poses significant implementation challenges without having the expertise to devise improved implementation or design alternatives.
- Level 2 (Understanding – indicated with "U" in tables below) implies a thorough mental grasp and comprehension of a concept or topic. Understanding typically requires more than abstract knowledge. For example, a surveyor with an understanding of boundary law should be able to identify and communicate legal issues arising from a practical case study.
- Level 3 (Ability - indicated with "A" in tables below) is a capability to perform with extraordinary competence as in areas of research and development.

Knowledge Depth

In this body of knowledge these three levels of knowledge depths and the previously discussed competencies are used to construct the matrix of required knowledge. Table 2 shows the surveying positioning knowledge matrix with suggested levels of competency for each category. The required level of competency for surveyors using basic positioning methods is relatively straightforward. It is recommended that every surveyor acquires this basic knowledge. However, the

	Undergraduate Degree	Professional Education	Post Baccalaureate Certification	Graduate Degree
Basic user	R	P	—	—
Specialist	R	R	P	—
Scholar	R	P	P	R

R = required; P = preferred.

Table 1. Educational requirements for surveyors with respect to positioning competency.

required competencies under the roles of specialist and scholar are more involved. Not every specialist and every scholar has to master all the units in all the knowledge areas described above. However, a specialist or a scholar should have a higher competency in the specific area of their specializations. For example, a geodetic specialist and an engineering surveying specialist will have more advanced knowledge and abilities in different areas (such as knowledge of geodetic surveying principles and construction processes respectively) (Table 2).

Competency in Knowledge Area: Measurement	Core	Specialist	Scholar/R&D
1. Situational analysis	A	A	U
2. Technology and measurement regimen selection	A	A	U
3. Systematic error analysis	A	A	A
4. Application of mathematical models for data and information representation	A	A	A
5. Designing or applying survey control	U	A	A
6. Field survey	A	A	R
Competency in Knowledge Area: Data Analysis and Management			
1. Examine data for completeness	A	A	A
2. Post-processing for systematic and random error reduction and evaluation	A	A	A
3. Analyze data for precision; draw conclusions about accuracy	A	A	A
4. Determine if additional measurements are required	A	A	A
5. Integrate data from various sensors into a homogenous database	U	U	A
Competency in Knowledge Area: Adjustments			
1. Apply different adjustment procedures for data processing	A	A	A
2. Apply statistical and adjustment tools to improve quality of information being reported	U	A	A
3. Calculate integrity of networks and other geometries	U	A	A
4. Apply principles of geodesy	R	A	A
Competency in Knowledge Area: Coordinate Geometry			
1. Apply two-dimensional and 3D transformations	U	A	A
2. Determine projected coordinates	U	A	A
3. Determine geodetic coordinates	R	A	A
4. Determine positions of surveyed points	A	A	A
5. Determine position or configuration of designed points, lines, surfaces, and volumes	A	A	A
6. Determine areas and volumes	A	A	A
Competency in Knowledge Area: Information Extraction			
1. Report positions, lines, surfaces, and volumes	A	A	A
2. Report conclusions, deductions, and inductions	A	A	A
3. Create maps and reports that are project and "consumer-specific"	A	A	A
4. Use CAD/GIS to generate user products	A	A	A

R = recognition; U = understanding; A = ability.

Table 2. The level of competencies and the educational requirements suggested.

Summary

The positioning body of knowledge for surveying is defined as a subset of the broad definition of the entire surveying body of knowledge. Because surveyors may focus their professional practice on different aspects of surveying, and because positioning is also a broadly based area, the positioning body of knowledge is categorized according to the level of involvement or the degree to which a surveyor elects to engage in positioning activities. Three levels of involvement (and thus competencies) are defined. The first is a routine use and application of positioning, the second is a specialist in surveying who performs work that is above the level of routine knowledge of the core units and topics. The third role is scholar. For each one of these roles, the body of knowledge, the level of competencies, and the educational requirements are suggested.

Positioning is basic to most of the subareas within surveying. Thus, knowledge in the various competencies has to be high to attain the professional level of surveyor. While it is true that the future of surveying involves more analysis, information extraction, and even knowledge delivery to the clients and users of the data collected by the surveyor or under the supervision of the surveyor, the final responsibility and the expertise in determining how to apply technology to collect the data remains a key responsibility of the surveyor, even if it is done by others with or without highly automated tools.

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Imaging Body of Knowledge for the Professional Surveyor

Jim Bethel

ABSTRACT: This paper describes those aspects of the science and engineering of imaging which are relevant to the Surveying Profession. Since imagery in general, and earth imagery in particular, are ubiquitous in today's world many aspects of imagery should be known to the Surveyor. An outline is presented of those elements of imaging knowledge which should be known to varying degrees of thoroughness. A table explicitly conveys the level of competence needed by Surveyors in three categories of professional practice.

KEYWORDS: Imaging, photogrammetry, camera, LIDAR, mapping, adjustment, surveying, remote sensing

Introduction

Surveying professionals are involved in all aspects of two-dimensional (2D) and three-dimensional (3D) geopositioning, boundary retracement, construction set out, as-built determination, mapping, Geographic Information Systems (GIS), and control point networks for various applications. In today's digital world, imagery is ubiquitous and useful for many of the above-mentioned applications. When imagery is used in such applications it must be considered an engineering tool, with consideration given to calibration, error sources, adjustment, redundancy, and error propagation. A one-megapixel image is comparable to one million readings of horizontal and vertical angle from a transit or theodolite. To exploit such a dense source of geospatial information, one cannot neglect the underlying mathematical models and the inevitable systematic, random and (potential) gross errors present in such data. Good references for the material covered in this paper are Mikhail et al. (2001), Mikhail et al. (2005), and Wolf and Dewitt (2000).

Definition

The term *Imaging* refers to the capturing of a scene by means of light intensities, Image products are often 2D geometric projections of a 3D scene. The intensities can be from single or multiple, broad or narrow spectral bands. Such spectral bands are often in the visible range but can also arise in other portions of the electromagnetic spectrum. The imagery itself can be in hardcopy or softcopy (digital) form, and it can be in an original sensor coordinate reference frame or transformed into other useful coordinate reference frames. The underlying mathematical sensor models can arise from pre-calibrated metric sensors, or, in some cases, they can be reverse engineered using uncalibrated, nonmetric sensors. Of course, the formal name that goes with the subject of imaging, sensor calibration, and 3D scene reconstruction is *Photogrammetry*.

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Rationale

The rationale for including Imaging as a core component within the Surveying Body of Knowledge is that the surveyor will encounter imagery often in the course of professional practice and must be able to understand it and incorporate it in a responsible manner in his/her workflow. Examples of the most commonly encountered imagery are: aerial photography for mapping, rectified or orthorectified imagery and mosaics, high-resolution commercial satellite images, images from terrestrial mobile mapping vehicles, and intensity layers from laser scanning (aerial or terrestrial).

Geographic information systems (GIS) often include imagery layers, modern USGS (United States Geological Survey) quad sheets often include an imagery overlay, and county assessors often use imagery for tax assessment purposes, which include spatial or dimensional inferences. The surveyor may have to integrate his data into an imagery environment, or extract evidence from image sources, or subcontract topography extraction from photogrammetric contractors, and, therefore, he must understand contract specifications for photogrammetry. In all applications dealing with imagery, the surveyor can have an active, integral role in providing control points, control dimensions, or other inputs for registration and calibration. Not surprisingly there is always a section on photogrammetry in the Fundamentals of Surveying Exam for professional registration.

Following is an outline of Imaging knowledge areas and important sub-areas.

Imaging Knowledge Areas

Cameras and Photography

The most common source of imagery is the camera, producing a digital photograph.

- Metric versus nonmetric – Mapping cameras are delivered with calibration data, and such cameras must be periodically recalibrated. Other, nonmetric cameras can be used for metric applications, but must be calibrated by the user.
- Calibration – This includes the process of determining the internal geometry of a camera, consisting of focal length, principal point, and lens distortion.
- Camera geometry and characteristics – These are important aspects of the camera which influence resulting imagery, for example focal plane layout:linear array versus area array.
- Spatial resolution – The sampling distance at object scale, can be influenced by distance to object, intervening atmosphere, image motion, and optics quality. This is often described by a Modulation Transfer Function (contrast versus spatial frequency).
- Spectral characteristics – Spectral bands include panchromatic, red/green/blue, near infrared, thermal infrared, ultraviolet, and microwave. When sensing outside of the visible, "sensor" is more appropriate than "camera".

Radiometry, Detection, and Sensing

This knowledge area deals with the mechanics of the interactions between the illumination scene and the sensor to generate the required image intensities. It includes the following primary topics:

- Optics – Typically lenses and mirrors to focus illumination at a detector plane.
- Aperture, shutter, radiometry – The relation between scene illumination, size of entrance optic element, exposure time, and the sensitivity of the detector(s); other important aspects are electromagnetic spectrum, solar illumination, atmosphere, object surface reflectance, and signal versus noise.
- Image motion compensation – High vehicle speed and/or long exposure time will generate image smear unless compensated.
- Detector – Traditionally film, now often a charge-coupled device (CCD) or complementary metal-oxide-semiconductor (CMOS) area array, with readout and storage facility Such detectors may include color filters, such as the Bayer filter, for color sensing.

Frame Geometry

Because frame camera geometry is the predominant camera type, a thorough knowledge of frame camera characteristics is necessary. Other camera geometries such as pushbroom or panoramic will be addressed elsewhere. The primary topics in this knowledge area are:

- Perspective geometry or pinhole camera – These are synonyms for the phrase "frame geometry."
- Graphical restitution using perspective – There is an entire subfield of photogrammetry dealing with 3D scene reconstruction using the laws of perspective. It is equivalent to, but more restricted than, conventional analytical photogrammetry.
- Scale and field of view – The concept of scale and field of view are very important to describe a particular image or camera.
- Relief displacement – This is an important characteristic of imagery from a frame camera, which describes one way in which an actual image differs from a map.
- Tilt displacement – This is an important characteristic of imagery from a frame camera which describes one way in which an actual image differs from a map.
- Interior and exterior orientation – This is how the detector sits in the sensor coordinate reference frame and how the camera sits in the object coordinate reference frame. These include both position and attitude.

Image Measurements

Traditionally image measurements were made on hardcopy imagery on a comparator, now they are typically made on a computer screen from digital imagery. This knowledge area is restricted to single image measurements and includes the following topics:

- Reference coordinate system – Typical reference coordinate systems used for measurements are pixel coordinates (row, column or line, sample), which may be directly related to detector elements or may be arbitrary, as in

the case of scanned film transparencies. Two-dimensional coordinate transformations will be needed to relate such arbitrary systems back to a sensor related system. Depending on these choices and the measurement environment, the units might be pixels or millimeters.
- Systematic errors and correction – Systematic error correction, sometimes called image coordinate refinement, consists of shifting the coordinates so that the origin is at the principal point and rotation to align with sensor, and then correcting for the effects of lens distortion.

Stereoscopy and Parallax

This area's focus is viewing and measuring images in pairs (stereo pairs). Its topics describe the design and implementation of stereo measurement environments with favorable height measurement geometry. They include the following:
- Depth perception and parallax – X-parallax (parallel to the base) is perceived as depth, Y-parallax is perceived as misorientation and should be eliminated by refining the math model.
- Base height ratio and vertical exaggeration – A base height ratio producing a 3D model with "normally" appearing aspect ratio is from 0.15 to 0.30. Higher base height ratios lead to vertical exaggeration and to increased height measurement precision. A typical value for topographic mapping applications is 0.6.
- Stereoscopes – Stereoscopes for 3D measurement environments can implement the left/right channel separation by: separate optical paths, anaglyph (red/blue), high frequency shutters, and by various polarization schemes. Most of these require the user to wear special glasses. Lenticular arrays permit stereo viewing without glasses, with the restriction of limited head movement.

Mathematical Modeling and Analytical Photogrammetry

In the past, special instruments enforced the geometry required for stereo extraction. Currently, most photogrammetric operations are carried out on general-purpose computers, and an essential element of this process is the use of a mathematical model to describe the sensor and its trajectory while acquiring images. Primary topics included in this knowledge area are as follows:
- Collinearity equation – Ray projection in a frame camera between ground point and corresponding image point.
- Coplanarity equation – Basic two photo equation relating conjugate image points, for triplets one also needs the scale restraint equation.
- Object space coordinate systems and transformations – Basic Cartesian object space coordinate system and transformations and projections to other commonly used coordinate systems.
- Image resection – Determination of camera position and orientation by means of control points in the image.
- Space intersection – Multi-image, multiray intersection to determine object space coordinates from conjugate image points.
- Bundle block adjustment – Multi-image, multipoint, simultaneous resection and intersection.
- Relative and absolute orientation – Orientation of a pair of photographs and subsequent registration of the resulting model to some object coordinate system.
- Independent models, strip formation, adjustment by polynomials – Model formation by pairwise relative orientation, linking by 3D rigid body transformations to yield strip coordinates, followed by registration to object coordinates by low order polynomials; models can also be linked by simultaneous rigid body transformations both along and between strips.
- Platform and trajectory modeling – Sensor position and attitude as a function of time, often aided by global positioning system (GPS) and inertial navigation system (INS) in modern operations.

Computer Vision

Many new approaches to automated image exploitation have been introduced in the recently developed field of computer vision. There is a closely related field of synthetic image generation or computer generated imagery (CGI). Among the primary topics in this knowledge area are:
- Homogeneous coordinates – A common feature of almost all work in the computer vision field is the use of homogenous coordinates which involves the use of an additional coordinate component. Common transformations can be represented by matrix multiplication, and points at infinity are accommodated.
- Fundamental and essential matrices – In the computer vision equivalent of the coplanarity equations, these matrices appear.
- Eight point algorithm – An approach to the relative orientation problem which has the advantage of being linear, therefore noniterative.
- Synthetic image generation – Useful for visualization and animation, this technique projects

a scene decomposed into polygons into a synthetic image, with illumination and texture.
- Automation and feature extraction – Various techniques to move from low level features to high level features, establish correspondences, and thereby reconstruct 3D scenes.

Estimation, Adjustment, Statistics, and Error Propagation

The fundamental techniques to reconcile redundant, inconsistent measurements into unique parameter estimates often use least squares. This is done by adding corrections to each measurement while simultaneously minimizing the magnitude of the corrections. If distributions and statistics are known about the input measurements, then hypothesis tests and confidence statements can be made about the results. Statistical inferences about the results of adjustment are referred to as error propagation. The primary topics included in this knowledge area are:
- Measurement errors – This includes random, systematic, and gross. Random errors are handled by adjustment, systematic errors are handled by compensation and modeling, and gross errors are handled by detection and removal.
- Objective functions and adjustment – If observations can be assumed normally distributed then least squares is the optimal objective function; if not then other objective functions will be preferable, such as least sum of absolute values.
- Functional and stochastic models – The functional model consists of the equations and the stochastic model consists of assigning all variables as either constant, unknown, or observed with known variance or covariance.
- Least squares techniques – Depending on the choice of parameters to carry, least squares can be done by observations only, indirect observations, or the mixed model (general least squares). The first two methods are actually just special cases of the third.
- Constraints – Constraints are functional relations to be enforced exactly between the parameters in an adjustment.
- Error propagation, hypothesis testing, and confidence statements – These are quantitative ways to statistically evaluate and characterize the results of an adjustment.
- Unified least squares – This is a technique to allow prior knowledge about the value and uncertainty of the parameters to be rigorously enforced.
- Sequential estimation and kalman filter – When observations are being generated continuously, as in a moving vehicle, these techniques provide a way to perform least squares tracking, and to obtain real time position, attitude, and covariance data.
- Robust estimation – Robust methods yield reasonable parameter estimates in the presence of gross errors. They work by detecting such blunders and removing them from the adjustment. Examples include data snooping, iteratively reweighted least squares, and L1 norm minimization.

Stereo Restitution

Manual and semi-automated stereo feature extraction requires an environment in which they can be carried out. Historically, such an environment was created on special purpose machines. These were replaced by desktops with some kind of stereo image display. The primary topics included in this knowledge area are:
- Analytical projection – The equations implemented in real time loop of digital stereo workstations are usually the collinearity equations, assuming a frame camera model.
- Digital stereo workstation – This is a computer environment with stereo display and 3D cursor for 3D object reconstruction.
- Pairwise rectification – Epipolar resampled images allow a parallax free view of the stereo model everywhere simultaneously.

Rectification and Resampling

Images are rectified, i.e., projected geometrically into a new grid for a variety of reasons. In the digital world this is always done by resampling which encompasses:
- Interpolation and aggregation – Upsampling and downsampling, respectively, require these two techniques of resampling a digital image.
- Nyquist sampling theorem and aliasing – When resampling, one must take at least two samples per period of the highest spatial frequency present. If this is not done, then the result is aliasing, or the introduction of artifacts into the new image which were not present in the original.
- Simple rectification – This is correction of the image for camera tilt.
- Ortho rectification – This is correction of the image for both camera tilt and terrain.

- True orthorectification – This is correction of the image for camera tilt, terrain, and building displacement.

Mapping and Cartography

When producing engineering maps, one has to follow certain conventions. These typically involve symbology, scale, projection, and included features. The primary topics in this knowledge area are:

- Enlargement factor versus contrast and spatial resolution – Large scale aerial photos permit very high enlargement factors. Small scale photos permit only much smaller enlargement factors. This is due to the intervening atmosphere degrading the contrast and therefore the spatial resolution.
- Map projections and reference coordinate systems – Engineering maps are always conformal, and common reference coordinate systems are chosen, such as state plane, or Universal Transverse Mercator.
- National map accuracy standards – Such standards are maintained by the U.S. Commerce Department and by professional organizations. They strictly apply to hardcopy maps, and apply to digital maps when displayed at specified scales.
- National map series – Such series may consist of 1:100,000, 1:50,000, and 1:25,000. In the U.S., they are 1:62,500 and 1:24,000.
- Urban and project oriented mapping – Larger scales are needed for urban areas and for engineering design. Specifications would be chosen to suit the project.
- Software environments – Software environments for map data collection, editing, and presentation are often standardized within an organization. Digital mapping software with attributes, topology enforcement, query, and spatial processing has evolved into GIS systems and software.

Topography and Digital Elevation Modeling

Accurate terrain representation is an essential feature of topographic maps. Historically, this was accomplished by direct drawing of contours from a stereo model; today, it is more common to construct a digital elevation model (DEM), with contours being a byproduct. This knowledge area's primary topics are:

- Grid/raster collection – For large area databases, whose components must align seamlessly, often a grid structure is chosen for the DEM.
- Unstructured point collection – For project level databases, a more efficient approach is variable density point collection depending on the terrain.
- Triangulated irregular network (TIN) processing – If unstructured points are collected, they are often processed and stored as a triangulated irregular network, consistent with Delaunay.
- Breakline processing – Where terrain slope discontinuities are present, breaklines along such discontinuities can force subsequent analysis algorithms to honor these features.
- Profiles and cross sections for road design – Road design often requires special topography collection with profiles along an alignment and cross section at right angles to the alignment.

Digital Photogrammetry

Although most imagery is digital, this phrase "digital photogrammetry" usually implies that some processing steps are automated. Some of the topics included in this knowledge area are:

- Image normalization – This is also known as epipolar resampling and is an aid to constrained image matching.
- Image matching – Matching can be carried out at signal level, by features, or by semiglobal methods using similarity metrics. Related algorithms include cross correlation, least squares matching, and dynamic programming.
- Constrained matching – This can be accomplished by techniques such as vertical line locus.
- Surface reconstruction, DEM generation – The most common application of matching is to generate the terrain surface by semiautomation.
- Automatic relative orientation – Interest point detection followed by matching permits the relative orientation process to be automated.

Project Planning

Project planning involves selecting camera specifications, flightline layouts, exposure station selection, and control point or auxiliary sensor selection. These tasks are accomplished under the following topics:

- Accuracy requirements – Accuracy dictates many of the choices made in project planning.
- Control point selection – Location and possibly premarking or signalizing of the control points must be done, but the details depend on whether kinematic GPS will be present in the aircraft.
- GPS/INS supported imaging – If kinematic GPS and INS are present in the aircraft, then much reduced requirements for ground control points are indicated.

- Flightline layout – Fewer and longer flight legs versus more and shorter ones are preferable if the project area can accommodate them.

Close-Range Photogrammetry

There are numerous applications in industry where terrestrial photogrammetry is attractive for 3D point determination. These include manufacturing, construction, medicine, forensics, and law enforcement. The math models powering these applications are basically the same as for aerial applications, but in practice, close-range photogrammetry differs with regard to equipment, illumination and data collection methods. The primary topics in this knowledge area are:

- Nonmetric cameras – In practice there are few choices for purchase of calibrated cameras so the user must be able to accomplish the calibration on his own.
- Optics selection, self-calibration – One should always choose optics without moving parts, so zoom lenses are discouraged. Calibration parameters can be estimated within the bundle block adjustment when strong geometry is present.
- Fixed baseline rigs – There are mechanical rigs with camera mounts at the ends of a fixed baseline, usually mounted on a tripod, which facilitate the subsequent orientation solution.
- Structured light – Artificially projected texture can sometimes help with shape determination when dealing with untextured objects. Binary illumination patterns can be used to automate the matching process.

Satellite Photogrammetry

The existence of many sources of high-resolution imagery from cameras in space means that surveyors must be conversant with the use of such imagery. Popular Internet sites make such imagery ubiquitous. The topics most often encountered in this knowledge area:

- Orbit mechanics – Most imaging satellites are in polar orbits, and the orbit parameters dictate revisit times and camera attitude values.
- Coordinate systems – Earth centered fixed versus earth centered inertial coordinate systems, and the transformations between the two are important considerations.
- Time systems – Time and its definition becomes an important parameter for the typical pushbroom camera architecture of space cameras. Examples include atomic time, GPS time, universal time, sidereal time, and solar time.
- Projection models – Ground to image and image to ground projections are typically accomplished by either physical models or replacement models. Error propagation should always be considered when making such projections.
- Ephemeris and support data – Both approaches to projection require an understanding of the support data or metadata which vendors supply along with image data.

Remote Sensing

Multi and Hyperspectral imagery can be very useful in making inferences about land cover, land use, and vegetation characteristics. One must consider the inevitable tradeoff between spectral resolution and spatial resolution when making image choices. Primary topics included in this knowledge area are as follows:

- Spectral coverage – Location of bands within the electromagnetic spectrum, individual bandwidths, and number of bands all have influence on the utility of such imagery.
- Classification – Semiautomated methods of supervised classification permit the leveraging of limited pixel labels to the entire image.
- Change detection – Images acquired over the same geographic location at different times permit automated detection of changes in land cover/land use.

Active Sensing with Lidar

Lidar and laser scanning have become very popular. If the Lidar sensor detects an intensity for each data point, then viewing the point cloud can have the appearance of viewing an image. There are now also “range cameras” which detect both range and intensity in a focal plane rather than by mechanical scanning. The primary topics included in this knowledge area are:

- Acquisition platforms – Lidar sensors can be mounted on aerial vehicles, terrestrial vehicles (mobile mapping), and static platforms (tripods, etc.).
- Point cloud processing – Registration of point clouds to each other, registration to control points, and filtering of vegetation and urban features are important processing steps.
- Feature extraction – Extraction of building footprints and roadway features from aerial lidar can automate some mapping functions.
- Mobile versus static data acquisition – Data collection from any mobile platform requires that

Imaging Knowledge	Core	Specialist	Scholar/R&D
Knowledge Area: Cameras and Photography			
Metric versus non-metric	U	U	A
Calibration	U	U	A
Camera geometry and characteristics	R	U	A
Spatial resolution	U	U	C
Knowledge Area: Radiometry, Detection, and Sensing			
Optics	R	U	A
Aperture, shutter, radiometry	R	U	A
Image motion compensation	R	U	A
Detector		U	A
Knowledge Area: Frame Geometry			
Perspective geometry or pinhole camera	U	U	A
Graphical solutions using perspective		U	A
Scale and field of view	U	U	A
Relief displacement	U	U	A
Tilt displacement	U	U	A
Interior and exterior orientation	R	U	A
Knowledge Area: Image Measurements			
Reference coordinate system	R	U	A
Systematic errors and correction	R	U	A
Knowledge Area: Stereoscopy and Parallax			
Depth perception and parallax	U	U	A
Base-height ratio and vertical exaggeration	U	U	A
Stereoscopes	U	U	A
Knowledge Area: Mathematical Modeling and Analytical Photogrammetry			
Collinearity equation	R	U	A
Coplanarity equation	R	U	A
Object space coordinate systems and transformations	A	A	A
Image resection	R	U	A
Space intersection	R	U	A
Bundle block adjustment	R	U	A
Relative and absolute orientation	R	U	A
Independent models, strip formation, and adjustment by polynomials	R	U	A
Platform and trajectory modeling	R	U	A
Knowledge Area: Computer Vision			
Homogeneous coordinates	R	U	A
Fundamental and essential matrices		U	A
Eight point algorithm		U	A
Synthetic image generation	R	U	A

R&D = research and development; R = recognition; U = understanding; A = ability.

Table 1. Imaging knowledge areas and sub-areas by level of proficiency.

Imaging Knowledge	Core	Specialist	Scholar/R&D
Knowledge Area: Computer Vision			
Automation and feature extraction		U	A
Knowledge Area: Estimation, Adjustment, Statistics, and Error Propagation			
Measurement errors	A	A	A
Objective functions and adjustment	A	A	A
Functional and stochastic models	A	A	A
Least squares techniques	U	A	A
Constraints	U	A	A
Error propagation, hypothesis testing, confidence statements	A	A	A
Unified least squares	U	A	A
Sequential estimation and kalman filter	R	U	A
Robust estimation	R	U	A
Knowledge Area: Stereo Restitution			
Analytical projection	R	U	A
Digital stereo workstation	U	U	A
Pairwise rectification	R	U	A
Knowledge Area: Rectification and Resampling			
Interpolation and aggregation		U	A
Nyquist sampling theorem and aliasing		U	A
Simple rectification (tilt correction only)	U	A	A
Ortho rectification (tilt and terrain correction)	U	A	A
True orthorectification (tilt, terrain, and building correction)	U	A	A
Knowledge Area: Mapping and Cartography			
Enlargement factor versus contrast and spatial resolution		U	A
Map projections and reference coordinate systems	A	A	A
National map accuracy standards	A	A	A
National map series	A	A	A
Urban and project oriented mapping	A	A	A
Software environments	A	A	A
Knowledge Area: Topography and Digital Elevation Modeling			
Grid/raster collection	U	A	A
Unstructured point collection	A	A	A
Triangulated irregular network processing	A	A	A
Breakline processing	A	A	A
Profiles and cross sections for road design	A	A	A
Knowledge Area: Digital Photogrammetry			
Image normalization		U	A
Image matching	R	U	A
Surface reconstruction, DEM generation	U	U	A
Automatic relative orientation		U	A

Table 1. *(Continued).*

Imaging Knowledge	Core	Specialist	Scholar/R&D
Knowledge Area: Project Planning			
Accuracy requirements	R	U	A
Control point selection	U	A	A
GPS/INS supported imaging	R	U	A
Flightline layout	R	U	A
Knowledge Area: Close-Range Photogrammetry			
Nonmetric cameras	R	U	A
Optics selection, self-calibration	R	U	A
Fixed baseline rigs		U	A
Structured light		U	A
Knowledge Area: Satellite Photogrammetry			
Orbit mechanics		U	A
Coordinate systems	U	A	A
Time systems	U	A	A
Projection models		U	A
Ephemeris and support data	R	U	A
Knowledge Area: Remote Sensing			
Spectral coverage		U	A
Classification	R	U	A
Change detection	R	U	A
Knowledge Area: Active Sensing with Lidar			
Acquisition platforms	A	A	A
Point cloud processing	U	A	A
Feature extraction	R	U	A
Mobile versus static data acquisition	U	A	A
Standards and quality issues	A	A	A
Knowledge Area: Applications			
Mapping	A	A	A
Resource inventory	U	A	A
3D object reconstruction	U	A	A
Medical applications		U	A
GIS database population	A	A	A

Table 1. *(Continued).*

attention is given to accurate estimation of the position and attitude trajectory. This requirement places the surveyor and geodetic engineer at the center of Lidar data quality.

- Standards and quality issues – Because Lidar is still a relatively new technology, there are not, at present, pervasive standards for Lidar data quality. This makes it more difficult for users and producers of data to guarantee the suitability of such data for particular uses.

Applications

Geomatics professionals would find it very useful to know how imagery can improve geomatics and surveying applications. A brief list of such applications follows:

- Mapping – 2D, 2.5D, and 3D mapping are the real workhorse applications for imagery.
- Resource inventory – Examples of resource inventory include coal piles, woodchip piles,

agricultural crop assessment, and forest and timber assessment.

- 3D object reconstruction – Industrial applications employing imagery to reconstruct 3D objects include shipbuilding, airframe manufacture, tooling quality assurance, forensics, and accident investigation.
- Medical applications – Examples of medical applications include: prosthesis fitting, tumor assessment, movement documentation, and dental appliance fitting.
- GIS database population – Ultimately most data destined for large scale GIS databases is acquired from controlled imagery.

Summary

Imagery is encountered at many points during the practice of surveying; hence, surveying professionals must be conversant with the fundamentals of imaging so that they can exploit this resource. Professional surveyors would also benefit from knowledge of more advanced concepts and their practical application, as needed. Many powerful imaging tools have migrated to personal computers. While there is no expectation for surveyors to have expert knowledge of these tools, nevertheless, they do provide the opportunity for broadening surveyors' involvement in the geospatial field and, consequently, expanding their customer base. Many projects are multidisciplinary in nature and require the optimum use of many technologies: GPS, total stations, levels, laser scanning, and photogrammetry. A surveyor who is familiar with all of these technologies will be in a better position to provide practical solutions to clients. In Table 1, the imaging knowledge areas and sub-areas are listed with the level of proficiency needed by all surveyors (core), surveyors specializing in image applications (specialist), and surveyors in academia (scholar/R&D).

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Surveying's Legal Body of Knowledge

Wendy Lathrop and Jeffery N. Lucas

Introduction

U.S. Labor Department statistics for 2008 indicate that there are approximately 857,000 geospatial occupations in the United States. Of that number, 58,000 are licensed surveyors—only about 6.7 percent of the geospatial occupations. There can be no arguing that licensed land surveyors are a very small percentage of the overall geospatial community, which includes geographic information systems (GIS) practitioners, remote sensing specialists, cartographers, photogrammetrists, and technicians in various disciplines. However, with the exception of a few states that license photogrammetrists, surveying is the only discipline within the geospatial community that is required by state law to be licensed, and that license is tied directly to the surveyor's role in dealing with property boundaries and the property rights attached to those boundaries.

Should those responsible for educating future surveyors fail to properly educate future professionals in the law of boundaries, easements, evidence, torts, equity, and other areas of the law as it relates to property rights associated with the proper location of property boundaries, the surveyors' "exclusive privilege of marking boundaries" will certainly be turned over to others more qualified, or deemed more qualified, to do so (Brown 1961). The numbers from the Labor Department seem to indicate there are plenty of alternatives to resolving the property boundary location problem if surveyors do not know or understand property law.

Indeed, the practicing surveyor's misunderstanding of the requirements of the law and evidence, the surveyor's fabrication of arbitrary rules of surveying, and the surveyor's confusion over his or her duties and responsibilities under the law and practice will almost certainly lead to the development and broad acceptance of other methods to locate property boundaries and adjudicate disputes. Eventually, the surveying profession will be bypassed altogether in favor of cheaper and less cumbersome ways of resolving property boundary location problems. This is already happening in some parts of the country.

Knowledge of the law is not only significant but is a crucial element of the overall surveying body of knowledge. Of all of the activities that fall under the umbrella of "surveying," the surveyor's interaction with the law and how the law relates to property rights—specifically property rights associated with the location of property boundaries—is the only justification for requiring surveyors to be licensed under the vast majority of jurisdictions, if not all of them. If the surveying profession wishes to retain its privileged and regulated status, it must do more to properly educate future surveyors in the law, including property law, the law of boundaries, associated property rights, rules of evidence, proper practice and procedures, and professional ethics and conduct.

The business of surveying itself and the technical components of surveying are also vested in legal knowledge. The professional must know how to properly establish and operate a business, interact with clients and employees, and comply with technical requirements of a project—all of which are addressed and guided by close familiarity with the law.

The surveyor must understand the terminology of the legal arena, as the legal meaning of a term may differ from its common non-legal usage. Further, the surveyor must be familiar with legal terminology in order to understand the legal decision-making process. The practitioner must understand the legal process and court system, and the priority of laws when they conflict between levels of government or even between same-level agencies. It is only when situations or laws are ambiguous that rules of "construction" apply, and the surveyor must understand the significance of such rules. Finally, the surveyor must understand that there is a difference between an outcome governed by strict application of law and an outcome that is founded in equity. Out

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of all this, the surveyor develops the ability to see and comprehend multiple and opposing viewpoints of the same situation, the capacity to follow legal reasoning, and facility in creating and critiquing legal arguments. Besides applicability to daily practice, such skills support the surveyor during preparation for trial, particularly in understanding the multiple significances of both questions and responses during depositions and court testimony.

Definition

The Surveying Body of Knowledge (BoK) related to the law is comprised of four main areas: legal systems, legal research, business, and practice. Of these, the most readily identifiable to non-surveyors is the area of law and regulated practice of the profession, but this is but one component of the larger body of knowledge guiding the work of the professional surveyor.

Overall, the legal BoK comprises familiarity with the law as it pertains to surveying principles and practices. At its core, this entails recognition of legal systems and processes, including court systems and civil procedures, and an ability to weigh evidence and follow proper procedures. With regard to legal resources, the surveyor needs the ability to conduct legal and courthouse research and an understanding of administrative, statutory, and case law. The law as it relates to the business of surveying includes recognition of copyright law, business entities, employment law, taxation, including a core understanding of contracts, errors, and omissions, and professionalism and ethics. It is essential that the practitioner be able to write and communicate well. The law and the practice aspects of surveying require a core understanding of liability, equity, torts, and remedies. Surveyors must understand real property law and expert witness testimony and reports, and must have the ability to deal with boundary law, easements law, water boundaries, survey reports and opinions, and mediation and boundary agreements. Finally, many technical aspects of practice are defined by laws, including geospatial reference systems for gathering and reporting data for specific purposes, location and type of monumentation that the surveyor must set, the details of recording plats, the specific details of site plans and allowable disturbances of wetlands, and the procedures for securing right of entry onto adjoining properties when such laws exist.

Specialists and scholars in the law aspects of the Surveying BoK must possess deeper understanding and abilities in all of these areas. Summary Table 2 at the end of this article outlines these various needs at the general practitioner, specialist' and scholar levels.

Rationale

The necessity for surveyors to be conversant in the law is found in the law itself. In New Jersey, the legislature has defined the practice of surveying as follows:

> The term "land surveyor" as used in this chapter shall mean a person who is a professional specialist in the technique of measuring land, educated in the principles of mathematics, the related physical and applied sciences, and *the relevant requirements of law*, all requisite to the practice of land surveying as attested by his license as a land surveyor. *[Emphasis added]* (New Jersey Statutes 2011a)

And in Maryland it is defined as:

> "Practice land surveying" means any service, work, documentation, or practice, the performance or preparation of which requires the application of special knowledge of the principles of mathematics, the related physical and applied sciences, and *the requirements of the relevant law*, as applied to: [list of defined activities follows] *[Emphasis added]* (Annotated Code of Maryland 2011)

Requirements for familiarity with and understanding of "relevant law" are not specific to these two eastern states that happen to lie in close proximity to one another. Texas, originally under Mexican and Spanish rule before gaining statehood and incorporating traces of those earlier legal systems into its own, includes knowledge of relevant laws in the defined scope of professional surveying (Annotated Code of Texas 2011). Even further west, Alaska defines the practice of surveying as incorporating "any service or work the adequate performance of which involves the application of special knowledge of the principles of mathematics, the related physical and applied sciences, and the relevant requirements of law for adequate evidence of the act of measuring and locating land. . ." (Alaska Statutes 2011).

The typical rationale articulated for regulating the surveying profession through licensure is reflected in California law.

> In order to safeguard property and public welfare, no person shall practice land surveying

> unless appropriately licensed or specifically exempted from licensure under this chapter, and only persons licensed under this chapter shall be entitled to take and use the titles "licensed land surveyor," "professional land surveyor," or "land surveyor," or any combination of these words, phrases, or abbreviations thereof. (California Business and Professions Code 2011)

Relevant excerpts from Pennsylvania law express this same concept.

> In order to safeguard life, health or property and to promote the general welfare, it is unlawful for any person to practice or to offer to practice . . . land surveying, unless he is licensed and registered under the laws of this Commonwealth as a professional land surveyor. . . . (Pennsylvania Code 2010).

Most states articulate a similar rationale. The typical legislation to regulate surveying activity creates a regulatory board and grants that board rule-making authority to further the objective of protecting the health, welfare, and property of the citizens of the state. These boards generally adopt rules ranging from basic definitions to procedures for licensing and disciplining practitioners. These boards either adopt a legislatively mandated definition of "surveying" or "land surveying," or they define the activity constituting regulated surveying practice themselves.

The Florida Administrative Code provides the following definition of surveying:

> As used in this chapter, the following terms have the following meanings: . . . (10) Survey: the orderly process of determining facts of size, shape, identity, geodetic location, or *legal location* by viewing and applying direct measurement of features on or near the earth's surface using field or image methods; defined as follows according to the type of data obtained, the methods used, and the purpose(s) to be served. *[Emphasis added]* (Florida Administrative Code 2010)

The Code of Massachusetts Regulations (administrative code) provides for procedural standards for conducting cadastral, original, and retracement surveys. Under the procedural standards for any such survey, when the surveyor draws conclusions and publishes the results of a survey of property, the surveyor shall:

> Make interpretation of location [or the property boundaries] in accordance with *law and/or precedent*, and finalize the establishment of the property boundary. *[Emphasis added]* (Code of Massachusetts Regulations 2011)

It is abundantly clear from these and similar laws and regulations in other jurisdictions that the surveying profession is licensed for the primary purpose of protecting property rights associated with the ownership of land. The small sampling of definitions provided above is indicative of the definitions of the licensed practice of surveying that have been adopted by the various licensing boards across jurisdictions. These definitions make it equally clear that the activity being licensed is the location of property boundaries, when new property is first created out of larger tracts (original surveys), and the reestablishment of the location of existing property boundaries (retracement surveys for legal location).

Curtis M. Brown made the same observations about the role of the surveyor under the licensing and regulatory rubric in his 1961 paper entitled, "The Professional Status of Land Surveyors" (Brown 1961):

> One of the reasons for giving surveyors the exclusive privilege of marking boundaries is to prevent the unskilled from monumenting lines that encroach on the bona fide rights of others.

To accomplish these ends, surveyors must fully comprehend the relevant legal materials to uphold their legally prescribed responsibilities, both to identify those responsibilities and to know the legal requirements to fulfill them.

As a general proposition, there are only two professionals qualified under state law to determine the location of property lines on the ground. The first is the surveyor duly licensed under state law. By definition, it is the practice of surveying to "locate, relocate, establish or re-establish" property lines on the ground. The initial location or establishment of original property lines of newly created tracts, parcels, or lots is almost always the function of the licensed surveyor. This is what is often referred to as the "original survey" of property.

After this initial or original survey, the function of relocation or reestablishment of existing property lines is generally referred to as a "retracement survey." When the function is retracement of existing property lines, in the first instance it is again the responsibility of the licensed surveyor to give an opinion on the location of the property lines in question. Failing to correctly locate the property lines in question or bypassing the survey option altogether, the coterminous landowners can turn to the courts for an adjudication of their property line dispute. Therefore, the second professional qualified to determine the location of property lines on the ground is the judge presiding over a court of competent jurisdiction, as designated by the various state laws.

The two functions of the licensed land surveyor—that of the original surveyor establishing property boundaries for the very first time or of the retracing surveyor locating previous established property lines—have been visited and commented on by the courts in the various jurisdictions on many occasions. The vast majority of current day surveys of property boundaries by private practice surveyors is retracement surveying as opposed to original surveys. The courts in the various jurisdictions have made it abundantly clear as to what the surveyor's role is when it comes to retracement surveys.

> A survey of a description does not determine title to land but seeks to find and identify the land embraced within the description. In resurveying a tract of land according to a former plat or survey, the surveyor's only function or right is to relocate, upon the best evidence obtainable, the corners and lines *at the same places where originally located by the first surveyor on the ground*. The object of a resurvey is to furnish proof of the location of the original survey's lost lines or monuments, not to dispute the correctness of it. If the original corners can be found, the places where they were originally established are conclusive without regard to whether they were in fact correctly located. The priority of calls is, first, the natural monuments to which it refers; second, the artificial monuments the surveyor places to mark the boundaries; and, third, the courses and distances marked on the plat or survey. *[Emphasis provided, internal citations omitted.]* (*Gilbert v. Geiger,* 747 N.W.2d 188, 194, 2008)

> In making a resurvey, the question is not where an entirely accurate survey would locate the lines, but where did the original survey locate such lines. The object of a resurvey is to furnish proof of the location of the lost lines or monuments, not to dispute the correctness of or to control the original survey. The original survey in all cases must, whenever possible, be retraced, since it cannot be disregarded or needlessly altered after property rights have been acquired in reliance upon it. It is generally held, therefore, that a resurvey that changes lines and distances and purports to correct inaccuracies or mistakes in an old plat is not competent evidence of the true line fixed by the original plat. *[Internal citations omitted.]* (*Wood v. Starko,* 197 S.W.3d, 255, 261, 262, 2006)

Scores of similar citations from almost every jurisdiction could be added to the above. The point to be made is that the role of the licensed land surveyor in the establishment and retracement of property lines has been clearly defined by the legislature and the boards that administer licensure, and correctly interpreted and clarified by the courts. These are all legal issues that the practicing surveyor must be fully aware of and have a working knowledge of—if continued licensure of the surveyor under existing law is desirable.

In addition to the role the licensed surveyor plays in the legal location of property boundaries, the courts have also framed the question when it comes to the proper resolution of disputed boundaries. This is a two-part question of law and fact: the legal question to be answered is "what" is the boundary, and the factual question to be answered is "where" is the property boundary located on the ground.

The surveyor's primary role when retracing property boundaries is answering the factual question of "where" the property boundary is located on the ground. However, the factual question cannot be addressed without a proper understanding, determination, and/or professional opinion on the legal question of "what" the property boundary is. These issues can often be complex. Resolving property boundary disputes requires a proper interpretation of the Rules of Construction and the gathering and weighing of the best available evidence. The surveyor cannot accomplish this without proper education in the law of boundaries, evidence, procedure, and other related subjects.

Beyond real property law, the surveyor must know how to find and comprehend the various statutes, regulations, executive orders, and court decisions that affect every aspect of daily practice. Finding and reading the law answers the question of what it means to be a surveyor in each of the jurisdictions that regulate the profession. While significantly important to those licensed in a single state, commonwealth, or territory, those licensed in multiple jurisdictions must be careful to stay within the defined limits of practice and be proficient to the fullness of those limits.

Professionalism	Business Practice	Technical Practice
• Defined scope of professional surveying practice • Standards of care • Ethical standards • Definitions of malpractice and misconduct • Rules of Evidence regarding expert testimony	• Business formation • Taxes • Employee relations • Occupational Safety and Health Administration and various other health and safety regulations • Contracts and agreements • Torts • Rules of Evidence relating to record keeping • Mechanics' liens • Small claims court actions	• State plane coordinate systems • Calibration of instruments • Contents of maps and plats • Monumentation - acceptable materials and dimensions, location, recording • Filing of maps, deeds, and other records • Rules of Evidence regarding boundaries and monuments • Compiling and applying the various elements of conveyancing

Table 1. Examples of legal guidance within three main areas of surveying practice.

This is because what may be permitted under one surveying license may not be permitted under another. Maryland, for example, specifically allows (and expects) licensed professional land surveyors to prepare and design plans that include "road and street grades; sediment and erosion control measures; non-pressurized closed storm drainage and stormwater management systems; and open conduit storm drainage and stormwater management systems" when such work is "undertaken in conjunction with site development or subdivision" (Annotated Code of Maryland 2011). In nearby New Jersey, however, such design work is beyond what a professional land surveyor may undertake (New Jersey Statutes 2011b); rather, it is encompassed within licensed engineering. Performance of such tasks without an engineering license is termed "unlawful" (New Jersey Statutes 2011c) and subject to penalties and civil actions by the State Board of Professional Engineers and Land Surveyors (New Jersey Statutes 2011d).

Included in the defined scope of services that surveyors may perform within the states, commonwealths, and territories is an expectation that the licensed professional is familiar with laws relevant to practice in that locale. Even with dramatically different jurisdictional scopes of practice, as with the two states mentioned above, safeguarding the life, health, property, and wellbeing of the public is still the universal purpose of licensure, and such promotion of public welfare is included in the knowledge that the surveyor must have.

What surveyors do (and may not do) as licensed professionals and how to do it is bound up in a variety of legal materials. The law affects how surveyors interact with clients, with other surveyors, and with the various agencies with which they work. It establishes standards, both technical and professional, to which surveyors must practice. The law more broadly establishes standards for business practice, not specific to surveying. Table 1 illustrates a minute fraction of the ways in which the law affects surveying.

The guidance in Table 1 is not found in a single location. Instead, it is scattered throughout a variety of legislative, administrative, judicial, and executive documents. These are further divided along jurisdictional lines, from municipal to county to state to federal. To find the materials necessary even for the simplest of projects, the surveyor must know first that such legal guidance exists and must be adhered to, and next where that guidance can be found.

Both the range and depth of surveying are rooted in legal material. A curriculum preparing future surveyors must include familiarity with the legal system, what materials are available, and where to find them. Legal knowledge is not as ephemeral as the technology surveyors employ; the principles and very heart of surveying are legal in nature—"Where is the boundary?" "What activities may I legally undertake?" "What standards apply to this project?"—with mathematical and scientific components supporting and supplementing the mental and logical process of applying the law.

Description of Knowledge Areas, Units, and Topics

Knowledge Area: Legal Systems

Legal systems refer to the basic legal structures established by laws and processes under the various state and federal jurisdictions in the United States. A recognition and understanding of these systems is necessary for any field of practice closely associated with the law or any discipline that will often encounter these systems, as history has demonstrated the practicing surveyor will.

Surveyors must have a basic understanding of the legal structure that has been established in the United States for prosecuting and defending civil matters in civil court. The units and topics in this knowledge area arm the practitioner with recognition and understanding of what to expect when involved in civil litigation. They also prepare the surveyor to properly evaluate evidence and then support any reports or opinions resulting from that process.

1. Core Unit: Legal Methods and Processes

At some point, the surveyor may become involved in litigation, either as an expert witness or as a defendant in legal proceedings. The surveyor may also become the focus of Board of Registration complaints and disciplinary hearings. The outcome in either instance is influenced by the methods and processes available to the particular court or regulating body. Civil cases allow for legal remedies and remedies in equity; surveyors should understand the differences and how each approach is argued. Surveyors should also understand distinctions between forms of damages for which they may be found liable, and that assessed compensatory or actual damages may be far exceeded by punitive damages.

2. Core Unit: Court Systems

Surveyors should be familiar with state and federal court systems, understanding how a matter proceeds from trial court through appellate and supreme courts. Special courts such as land courts or chancery courts are important parts of the court system, and the distinction between law and equity must be understood. Jurisdictional matters related to the adjudication of various issues involving surveying, liability, contracts, etc. may determine which court hears a case, and the surveyor must be prepared to know whether to prepare to speak before a jury or a single judge.

3. Core Unit: Civil Procedure

Civil litigation is guided by Rules of Civil Procedure adopted by each state. These govern how a legal action is commenced, including filing a complaint, issuance of a summons, and service of the complaint to the defendant. Of particular importance to surveyors within these Rules are those sections covering discovery, the role of the expert witness, depositions, and trial testimony.

4. Core Unit: Evidence and Procedures

The surveyor's mission is to collect, analyze, and report evidence of many varieties. Surveyors must understand the evidence found in written and graphical documents, in the field, and from court records; know how to weigh evidence and formulate a professional opinion; and then identify the utilization of evidence in a written or graphical report or oral testimony.

Every surveyor must understand the role evidence plays in both civil litigation and surveying practice and procedure. This requires familiarity with various evidence standards utilized by the courts and procedures for weighing and evaluating evidence, including testimony, physical evidence, measurements, and record evidence. Topics or skills within this core unit include the following:

- Forms of evidence – The surveyor should know the forms of evidence and understand the classification and relative value of evidence as primary or secondary, *prima facie*, intrinsic or extrinsic.
- Rules of Evidence – The surveyor should understand the applicability of the rules in determining admissibility of evidence in court, qualifying as an expert witness, and limits of the expert's testimony.

Knowledge Area: Legal Resources

Surveyors must understand the differences between various legal materials and their usefulness, authenticity, or reliability for a given situation. Legal resources are the various assets available to the practitioner in dealing with the myriad of practice and procedural issues that will undoubtedly be encountered over the course of one's career as a surveyor. These are essential tools in fulfilling the professional, business, and technical demands of daily practice. The surveyor must be able to identify various resources and their authority, understand what the various resources contain, know where to find these various resources (and discern the authority of different formats of the same materials), and be able to distinguish between primary and secondary materials. Further, when it is found that laws or regulations conflict with each other, the surveyor should understand the priority of these documents and be prepared to determine a course of action to address and/or overcome this not uncommon situation.

The surveyor should be familiar with legal materials and law at every level of government, understanding what each contains, as well as when and how they affect the surveyor's work, including business operations, technical aspects, and professional practice. The same care and scrutiny should be applied to discovering how laws and other legal sources affect the surveyor's professional services as is applied to each piece of evidence that is gathered in the course of a survey.

1. Core Unit: Legal Research

All surveyors must be able to conduct basic legal research to find statutory law and appropriate administrative law or regulations controlling a given surveying matter or practice. Because court decisions may affect a particular boundary or establish professional responsibility, surveyors should also be able to find those opinions pertinent to their practice. A state's constitution may also enunciate that jurisdiction's boundaries, which is of prime concern to a surveyor working along those limiting lines. When serving as an expert witness, the surveyor's ability to conduct legal research is of great value to the entire legal team.

2. Core Unit: Courthouse Research

Courthouse research is an essential skill required to survey property. Surveyors must be able to conduct basic courthouse research within the local jurisdiction. This basic knowledge can be transferred to any jurisdiction where they may practice. Records beyond deeds found in a courthouse and containing information about land interests and boundaries include, among others, mortgages, lis pendens, road openings or vacations, and wills. The surveyor must know what to look for, where to find it, and how the found material affects the project at hand.

3. Core Unit: Statutory Law

The surveyor should understand how statutory law is created, the effect of amendments and repeals, and the applicability of laws in effect at various times. Both federal and state legislatures create statutes that affect the professional, business, and technical aspects of the practice of surveying. Among innumerable examples, these laws define terms related to real property interests, establish the scope of surveying practice within a jurisdiction, identify technical standards (such as the applicable state plane coordinate system), set forth the contents and recordation requirements of survey plats, and set time frames for limitations of actions related to contractual obligations and surveying errors.

At the local level, the municipal ordinance is the equivalent of a statute. Land use, zoning, and subdivision are the most commonly recognized ordinances affecting the use of land within a jurisdiction, but the surveyor may find that other ordinances are also applicable to a given project. The practitioner therefore must know how to find and apply those additional laws.

4. Core Unit: Administrative Law

Agencies created by state and federal legislation issue rules and regulations affecting the practice of surveying. Federal regulations affect federal property issues (including their boundaries and jurisdiction) that affect surveys within and abutting those lands. Federal regulations also serve as the basis for state regulatory agency rules and actions; examples include minimum criteria for managing land use within 1 percent-annual chance floodplains, highway and railroad safety standards, and the geometry of aerial glide path easements for airports. At the state level, agencies serving as local arms of federal agencies adopt the same or similar rules as their federal equivalents. Jurisdictional regulations also affect the actual practice of the surveying profession, including but not limited to licensing requirements, standards of practice (minimum technical standards), and codes of ethics.

5. Core Unit: Judicial Decisions and Common Law

Courts issue written opinions outlining their decisions and the reasoning behind them. Such judicial decisions may be based on legal precedent, but that precedent may be common law, which is comprised of both written court opinion and unwritten law from England. The surveyor should be able to find and study court cases, to analyze and report on such topics as, for example, boundary disputes, surveyor liability, boundary establishment doctrines, deed interpretation, and Rules of Construction. Judicial decisions may also explain the meaning of laws as an interpretation applicable to certain fact scenarios. The surveyor should be familiar with county, probate, state, and federal courts and know how to find their published opinions. The practitioner must also be able to recognize the difference between precedent-setting cases and those applicable only to a particular fact scenario, and when decisions from other courts and jurisdictions may be applicable. The ability to discern relevant opinions and the occasional poor court decision is also a valuable skill.

6. Core Unit: Executive Orders

The president of the United States and the governors of the various states and territories making up this nation all have the ability to issue orders that can affect the business and technical practices of surveying. While executive orders are not often recognized as affecting surveying, such orders can, for example, establish procedures or identify the purpose and focus of an agency's agenda. The surveyor should recognize the narrow or broad applicability of executive orders to the surveying practice and business.

Knowledge Area: Law and Business

Many practicing surveyors own and operate their own small businesses with a few employees or they are sole practitioners. Others work for larger firms and may never actually run a business. Nevertheless, understanding various aspects of the law as they relate to the business of surveying is essential to all practitioners. A vital element of surveying practice is the law as it relates to and affects business. Even if the surveyor is an employee of a large firm, basic recognition and understanding of many of the legal issues affecting business is essential to a successful practice.

Business owners and particularly managers must be familiar with a range of statutes and regulations affecting business practice, from the process of establishing a business through hiring and firing practices, through understanding the rights of the client versus the surveyor.

1. Core Unit: Writing and Communication

The surveyor must have a strong command of language, with the ability to communicate with colleagues, clients, and their legal representatives, employers/employees, public officials, judges and juries, adjoining landowners, and the public at large. This entails oral, written, and physical presentation skills. In every case, the surveyor must have clarity of expression, a thorough knowledge of the technical and legal terms associated with the topic, and good grammar. Topics or skills within this core unit include the following:

- Written communication skills – The practitioner must be able to prepare real property descriptions, survey reports and opinions for clients and the legal community, and expert reports. Other legal documents the surveyor must be able to prepare include contracts with clients, contractors, and employees, letters, and other correspondence. Because written communication can be reviewed and analyzed multiple times, and because even in-house materials can be subpoenaed for litigation purposes, the surveyor must be particularly aware of the language (including punctuation that may change meaning) in any written document prepared for either internal or external use. Good grammar, proper spelling, and appropriate use of language add to the professional tenor of any written material. Graphical reports in the form of survey plans and exhibits for public presentations and court appearances are encompassed in this category of communication.
- Oral communication skills – These skills include appropriate expression in terms of chosen words and organization of thoughts to convey information relating to the practice of surveying and to expert opinions.
- Physical presentation skills – These skills include the appropriate use of exhibits and body language, ability to think and respond quickly but not speak before thoughts are fully formed, ability to present material and answer questions with different phrasing and formats to reach more of the audience, and the ability to handle difficult audiences calmly and courteously. Whether speaking to a single client in the office, making a presentation at a public meeting, or being deposed for a trial, surveyors must be aware of the impact of words and the influence of physical presentation, including personal appearance, use of visual exhibits, and flexibility in adapting language to the audience.

2. Core Unit: Contracts

The contract is an essential tool for memorializing an understanding between surveyors and their clients and between surveyors and those they hire either as employees or subcontractors. While the court may eventually determine that an unwritten contract is enforceable, it is far better practice and protection for all involved to have this agreement and its terms and conditions committed to writing. A contract may be held up to protect a surveyor or to pursue an action against a surveyor. The surveyor must understand the function of contracts and what makes them enforceable. Topics or skills within this core unit include the following:

- Nature and types of contracts, elements of contracts – What constitutes an enforceable contract; distinctions between contracts and agreements; applicability of the Statute of Frauds.
- Contractual obligations – Identification of the responsibilities of each party to a contract. This area includes cost predictions, payment scheduling, indemnification clauses, alteration or termination of contractual relationships and obligations, establishment of when and how a contract is considered completed and how contractual disputes will be settled, including arbitration, mediation, or judicial remedies.
- "Limitation of actions" statutes – How contracts affect the running of these laws and how these laws affect actions related to contractual obligations; distinctions between statutes of limitation and statutes of repose.
- Breach of contract – What constitutes a breach, and the legal remedies available to the client and to the surveying professional to enforce contracts, including small claims actions, mechanic's liens, and other court actions.

3. Core Unit: Torts

Outside of contractual responsibilities, a surveyor may be subject to other legal actions in the form of torts. The most common tort claims against surveyors are for negligence and for trespass, the former being alleged in varying degrees of responsibility from contributory to gross. Surveyors must understand what torts are to avoid being accused of tortious action, but also to properly argue such actions against clients, employees, or other parties. Topics or skills within this core unit include the following:

- Torts and remedies – Understand the various forms of torts and their legal implications; distinguish between tort actions and actions based on contractual relationships; understand the liabilities related to torts and the remedies available to those damaged by the tortfeasor.
- Negligence – As this is possibly the most common of tort allegations against surveyors, the professional must understand what constitutes negligence, the various forms of negligence, and the associated damages related to negligence.
- Standards of care – An understanding of how compliance or lack of compliance with established standards affects accusations of tortious activity against the surveyor. Determining if such standards exist when they are not committed to writing, and enforceability whether written or unwritten.

4. Core Unit: Copyright Law

Ownership of surveying products can raise substantial discord between surveyors and clients. The surveyor should be familiar with copyright laws and intellectual property laws affecting the product of a surveyor's efforts to identify what materials and products may be copyrighted and how to preserve copyright. The surveyor should also understand what materials relied on in the process of conducting a survey and preparing final products may be subject to copyright, and how to avoid infringing upon those copyrights.

5. Core Unit: Business Formation

The surveyor intending to form a business or join in the ownership of an existing business entity must have a firm understanding of the legal requirements for forming a corporation, limited liability company, sole proprietorship, or other of the various business organization forms available, and he for she should be able to weigh the advantages and disadvantages of one business form over others. The surveyor must also be familiar with partnerships and joint ventures, as well as distinctions between them for those times when such options for existing business entities to work together arise. Topics or skills within this core unit include the following:

- Business entities – Ability to discern the advantages and disadvantages of one form of business organization over others. This includes liability and taxation differences, required licensed individuals, and the ability to practice in more than one jurisdiction.
- Agency and partnership relationships – Understanding the relationship between agents, principals, and third parties, how such relationships are created, and the liability and authority of each party.
- Business formation – The laws related to business registration in parent and foreign states, employer identification numbers, and selection of accounting systems for taxable or disregarded entities.

6. Core Unit: Business Management and Operation

The daily operation of a business, whether solo practitioner or large corporation, requires familiarity with, and adherence to, laws relating to every phase of practice. Topics or skills within this core unit include the following:

- Employer/employee relationships – This unit requires familiarity with federal and state employment laws, including Americans with Disabilities Act, Equal Employment Opportunity laws, employment taxes and withholdings at local, state, and federal levels, workman's compensation laws, and legal recourses for both employers and employees regarding termination of employment.
- Special site requirements – Some projects may entail legal requirements for special training or practices to protect the site, the workers, or both. Examples include Occupational, Safety, and Health Administration (OSHA) regulations for confined spaces and hazardous waste sites, statutory requirements addressing provision of notice to adjoining owners prior to entering their land in the process of conducting a survey, and limitations of the width of cut survey lines through protected wetlands to avoid the need for a permit.
- Record keeping – Understanding appropriate record keeping, the effects of Rules of Evidence on record keeping and general business practice, and the significance of documenting the file on every aspect of business activity.
- Electronic and digital records – Legal recognition of such records and signatures, retention of such records, and the effect of Freedom of Information Acts on records kept and records sought.
- Tax laws – Business operators need familiarity with a variety of applicable laws, including business franchise taxes, taxable employee benefits, Social Security and unemployment taxes, filing W-2 and 1099 forms, quarterly estimated income tax payments, and filing deadlines.

7. Core Unit: Budgeting and Finances

The surveying business operator must understand the basics of budgeting to start and operate a small business, including operating capital, overhead, salaries, insurance, and leases or purchase of office space and equipment. Legal aspects in the arena of business operation include financial obligations, bankruptcy proceedings and reorganization, and rights of debtors and creditors. These topics are relevant whether directly related to the surveying practice or to those with whom the surveying practice has contractual relationships.

8. Core Unit: Professionalism and Ethics

Merely holding a professional license does not ensure professionalism in practice. "Professionalism" addresses the conduct of the individual, the manner of performing responsibilities, and interactions with others. Those who practice with professionalism do not take on work they are not capable of completing competently and ethically. Professional and ethical behavior includes fair competition for work and fair treatment of clients, employees, colleagues, and any others with whom the individual interacts. Thus ethics is a key component in achieving professionalism.

9. Core Unit: Liability

As Curtis M. Brown (1961) once said: "Professional liability is a privilege tending to prove the land surveyor's professional standing." Technicians do not incur much liability because the liability generally falls on the professional in charge. Along with professional recognition comes professional liability. Understanding and ability in the area of liability are essential for future practitioners. Topics or skills within this core unit include the following:

- Professional liability – General liability and professional liability distinguished.
- Limitations on liability – Statutes of limitations, discovery rule, and rules of repose relative to limits on the professional surveyor's liability.
- Standard of care – Legal and local standards of care for professional practitioners and the role such standards play in negligence actions, trial testimony, and expert witness services.
- Certifications – Appropriate language, enforceability, liability associated with certifications, legal limitations to certifications related to state-specific variations of the Uniform Commercial Code 2-318 regarding third party beneficiaries. Distinctions between certifications, guarantees, declarations, statements.
- Errors and omissions – Liability associated with errors, omissions, and negligence; insurance protection, exclusions, and conditions.

Knowledge Area: Law and the Practice of Surveying

The law and the licensed practice of surveying cannot be separated. An understanding of the law is essential: some aspects of the law and surveying require an ability on the part of the licensed surveyor to carry out the requirements of the law in order to render competent professional services.

The licensing mandate for surveyors absolutely requires the surveyor to know, understand, and apply the law in professional, business, and technical aspects of practice. Advanced understanding of and ability to conform to the law in practice are vital for the surveying profession to maintain its licensed status.

1. Core Unit: Professional Practice

The surveyor must know the definition of surveying within a given jurisdiction before undertaking work in order to determine whether a given project is within the realm of legal practice. In some instances a license may not be required for certain surveying work, but the practitioner must know what those exceptional circumstances are. Professional registration laws define misconduct, illegal practice, and the consequences of each. In establishing requirements before admittance to licensure within a jurisdiction, these laws outline the allowances and disallowances for comity or reciprocity of licensure between jurisdictions, as well as requirements for maintaining licensure, such as continuing education. Topics or skills within this core unit include the following:

- Licensure laws – This includes an understanding of requirements for acquisition and maintenance of professional licensure, and allowable practice under a license.
- Standards of practice – This includes an understanding of legally prescribed standards affecting surveying practice, including state board rules and other standards established by statute or regulation including but not limited to specific agency requirements. These include technical standards relating to how certain work is to be performed and reported. The surveyor must also understand the effects of local standards of practice and historical practice and methodology.

2. Core Unit: Land Use and Land Management Law

A significant proportion of many surveying practices is related to land development or redevelopment and environmental protection. Laws issued by local, state, and federal entities govern land use and land management, as well as the processes by which proposals for changes in the use or management of properties are submitted and approved. The surveyor must be familiar with statutes, regulations, and even executive orders guiding such activities. Although local ordinances offer the most immediately recognized guidance—in terms of identifying major and minor subdivision requirements, zoning restrictions, site plan development and off-site improvements or considerations— state and national laws also, for example, affect local floodplain management, wetlands, water quality protection, hazardous waste sites, and design and improvement standards. The surveyor undertaking any project must be able to find and conform to local, state, and federal requirements both to protect the site's environmental qualities and to satisfy the client's needs. Topics or skills within this core unit include the following:

- Land use and land management law – Laws found at every level of government from local to federal apply to the process of assisting clients with their land use and land management plans. From design to field work to preparation and presentation of documents required for approval of plans and projects, the surveyor must be aware of and adhere to legal requirements. Land use controls may include private controls, such as nuisance, lateral support, drainage and surface waters, restrictive covenants, access to public roads, and easements for light, air, and view. Public land use controls are those addressed by public laws, including planning, subdivision, zoning, nonconforming uses, open space preservation, historic preservation, road dedication, and other public purposes.
- Environmental law – Beyond the immediate parameters of a project, the surveyor is responsible for understanding the applicability of laws that protect habitat and water quality, warn for awareness of soil stability and cumulative effects of floodplain and stormwater management activities, and safeguard against the dangers present on hazardous waste sites, among other concerns and considerations.

3. Core Unit: Real Property Law

The evolution of society and the history of various elements of real property law have affected the application of laws over time, and understanding this context is important in determining intent of original grantors and grantees. Real property law is a large umbrella that includes the law of boundaries, easements, title to property, deeds, and legal descriptions. Because location of interests on the ground is directly related to who owns those interests, this area of law is central to the practice of surveying. The surveyor must be able to discern the intent of the original parties to deeds and other documents, not only through their plain language but also their context in time, place, and historical practice. Topics or skills within this core unit include the following:

- Estates, title, and interests in real property – This includes the ability to distinguish between the different interests an individual or entity may hold in real property, between ownership and possession, and between different forms of ownership and different forms of possession; and identification of freehold and less than freehold estates, determinable and defeasible interests, leaseholds, estates for years, reservations and exceptions, condominiums, and impacts on land use and transferability.
- Creation and termination of real property estates and interests – This requires an understanding of actions and conditions necessary for the different means of creating or extinguishing real property interests. The nonexhaustive list of means to accomplish these ends includes dedication, grants, donations, statutory proceedings, ordinances, charters, prescription, various court actions, and abandonment.
- Deeds and descriptions – The types and essential elements of deeds, including the caption, body, granting clause, habendum clause, covenants, and warranties. The surveyor must be able to understand the expressed intent of the parties in terms of interests conveyed and physical extent, including the "four-corners" doctrine and contextual meanings to know the appropriate application of intrinsic and extrinsic evidence. Rules of Construction, identification of ambiguities (latent and patent), forms of describing real property interests, and applicability to various fact scenarios must be understood.
- Conveying real property estates and interests – Written and unwritten means of acquiring and conveying real property interests must be understood to know how and when the Statute of Frauds applies to these transactions. This also includes wills, reversionary rights, and condemnation proceedings.
- Notice – An understanding of the various forms of notice and of the purpose of recording statutes, Marketable Title Act, Torrens and other land registration systems, and title insurance.
- Easement law – An understanding of what constitutes an easement or right of way to distinguish from other interests in real property, and how such interests are created and extinguished. Ability to distinguish between easements appurtenant and in gross, negative and affirmative, express and implied, easements by necessity and prescriptive easements is also included in this unit.
- Boundary law – The surveyor must have an in-depth comprehension of the doctrines of boundary law, including the interpretation of written documents, monuments and corners, junior and senior rights, and simultaneously created parcels. Surveyors should understand both metes and bounds systems and the Public Land Surveying System, as well as other land systems specific to the jurisdictions where they practice. Practitioners must also know how to address conflicts between boundary evidence, including apparent gaps, overlaps, and differences between record and physical evidence.
- Disputes between adjoining interest holders – This includes practical locations, boundary agreements, acquiescence, commissions, partition, and other dispute resolutions.
- Water law – This includes an understanding of the ambulatory nature of water boundaries, riparian and littoral rights, and apportionment; Public Trust Doctrine and ownership of submerged lands; effects of erosion, avulsion, accretion, and reliction; sovereign powers related to water bodies; understanding navigability or tidal nature of water in establishing title and "Waters of the State;" location of pierhead and bulkhead lines, and other jurisdictional matters relating to water bodies.

4. Core Unit: Expert Witness Testimony and Reports

Surveyors have specialized knowledge and expertise beyond the scope of the general public and attorneys. For this reason, surveyors are called upon to serve as experts in legal proceedings, but before doing so must know how to prepare to qualify and serve as an expert. The surveyor must know how to prepare for depositions and expert witness testimony at trial, and how to prepare affidavits and expert witness reports, while being aware of the "ultimate issue" rule.

Table 2 summarizes the level of understanding and ability to apply knowledge for the general

Knowledge Area/Unit/Topic	Core	Specialist	Scholar/R&D
Knowledge Area: Legal Systems			
1. Legal methods and processes	R	U	U
2. Court systems	R	U	U
3. Civil procedure	R	U	U
4. Evidence and procedures			
Forms of evidence	A	A	A
Rules of evidence	U	U	A
Knowledge Area: Legal Resources			
1. Legal research	A	A	A
2. Courthouse research	A	A	A
3. Statutory law	U	A	A
4. Administrative law	U	A	A
5. Judicial decisions and common law	U	A	A
6. Executive orders	R	U	A
Knowledge Area: Law and Business			
1. Writing and communication			
Written communication skills	A	A	A
Oral communication skills	A	A	A
Physical presentation skills	U	A	U
2. Contracts			
Nature and types of contracts, elements of contracts	R	U	A
Contractual obligations	U	A	A
"Limitation of Actions" statutes	R	A	A
Breach of contract	R	A	A
3. Torts			
Torts and remedies	R	U	U
Negligence	U	A	A
Standards of care	U	A	A
4. Copyright law	R	U	A
5. Business formation			
Business entities	R	U	R
Agency and partnership relationships	R	U	R
Business formation	R	U	R
6. Business management and operation			
Employer/employee relationships	R	A	U
Special site requirements	U	A	A
Record keeping	R	A	U
Electronic and digital records	R	U	U
Tax laws	R	U	R
7. Budgeting and finance	R	A	U
8. Professionalism and ethics	U	A	A
9. Liability			
Professional liability	R	A	U
Limitations on liability	R	A	A
Standard of care	U	A	A
Certifications	U	A	A
Errors and omissions	R	R	U

R = recognition; U = understanding; A = ability.

Table 2. Summary table.

Knowledge Area/Unit/Topic	Core	Specialist	Scholar/R&D
Knowledge Area: Law and the Practice of Surveying			
1. The professional practice			
Licensure laws	U	A	A
Standards of practice	U	A	A
2. Land Use and land management law			
Land use and land management law	U	A	A
Environmental law	U	A	A
3. Real property law			
Estates, title, and interests in real property	R	A	A
Creation and termination of real property estates and interests	U	A	A
Deeds and descriptions	U	A	A
Conveying real property estates and interests	R	U	A
Notice	R	U	A
Easement law	U	A	A
Boundary law	A	A	A
Disputes between adjoining interest holders	U	A	A
Water law	U	A	A
4. Expert witness testimony and reports	U	A	A

Table 2. *(Continued).*

practitioner, the specialist, and the scholar or research and development (R&D) individual.

Conclusions

Within the geospatial community, only the surveyor is required to be licensed by the state.[1] This license requirement is predicated on the state's desire to protect the health, welfare, and property of the citizens of the state and a recognition that licensed surveyors possess the skills and training necessary to accomplish that task. However, the practicing surveyor cannot properly protect real property and associated property rights without the requisite training, knowledge, and skills. Essential to this task is not only a recognition of the law as it relates to property rights, but an understanding beyond that of the ordinary geospatial practitioner and, in some instances, an ability to put the law into practice through proper applications and procedures. These tasks cannot be competently accomplished without a wider foundational knowledge based in such collateral issues as legal methods and processes, legal research, liability, professionalism, and ethics. All such knowledge and skills are applicable to professional practice, business operation, and technical aspects of surveying.

At its core, the practice of surveying is intimately tied to the law. From the process of acquiring a professional surveying license to proper assessment of a project's parameters to operation of an office, surveyors are daily guided and bound by local, state, and federal laws. Therefore, familiarity with the sources of law, the location of legal materials, and the ability to find, comprehend, and apply that material are central to the practice of professional surveying. Beyond personal knowledge of the law, the surveyor must also be able to clearly convey this information orally and in writing for the general public to understand the value of the skills and services that only the surveyor can provide. Communication skills and sound business practices are central to satisfying the public need while guarding against undue liability. All of this is bound to knowledge and application of the law.

A surveying BoK of the law must provide the basis for properly training, educating, and teaching the skills necessary for future surveyors to maintain their licensed status. If not, the task of positioning real property boundaries will be bestowed on others deemed more proficient, or on those who can provide services deemed no better and no worse than current survey practice but delivered at a much cheaper cost. The other alternative will be landowners completely bypassing the surveying process and going straight to ligation with their GIS-produced "property survey" in hand. Any of these alternatives will certainly put an end to the practice of surveying as it is currently known.

[1] There are a few states, such as Florida, that require the licensure of aerial photogrammetrists. This is a relatively small exception to the general rule.

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Surveying Body of Knowledge—Land Stewardship

Wendy Lathrop

Introduction

Our planet is made up of many finite resources, including water, land, flora, and fauna. It often falls to the surveyor to sort through a series of conflicting requests and requirements to serve the client, meet the needs of a regulatory process that guards the public health and safety, and simultaneously fulfill professional and ethical responsibilities to protect the environment.

The range of projects associated with land use, site development, and resource management varies widely, from accommodating environmental impacts of construction on pristine sites to locating the plume of pollution from toxic spills to planning and staking out subdivision layout or urban infill. When we speak of "site development" or "land development" in this section of the Body of Knowledge, we use these terms in a broad sense, encompassing more than the common perception of erecting buildings, installing utilities, and laying down pavement. Land development may be a project for the enhancement of outdoor recreational areas by planting additional trees, a design requiring appropriate locations for solar and wind facilities, or a plan to reduce wetland loss by creating bioengineered buffers and removing non-native invasive plants. An educated surveyor can play a vital role in the ever-expanding array of "environmental" projects that by their very nature must rely on professional surveying services. In most site development scenarios the surveyor is the first professional on the site, gathering the data that will be the basis of plans documenting existing predevelopment conditions. Such plans detail the resources and limitations that will affect each subsequent design plan throughout the design process.

Appropriate use and protection of resources associated with site development falls directly into this segment of the surveying body of knowledge. Which trees on site must be protected during building construction? Are the planned conservation easements located where they will best fulfill their mission? Have steps been taken to protect vistas and historical conditions that are part of the subject parcel? Will the plan destroy the last remaining viable habitat for wildlife within a 10-mile radius? We tend to forget that the reason we have wildlife "problems" is often because we have removed their feeding and resting places: the brushy meadow where deer used to sleep and graze is now a residential development with only hostas to graze upon. Or we have created newly attractive areas for creatures with which we don't particularly care to share our spaces: the man-made lakes on sprawling office complex properties are ideal for Canadian geese that find the lack of natural predators and easy access to the water very appealing.

Health matters are not always adequately considered in land development, or often only in an anthropocentric manner, such as, "What is the appropriate distance between wells and septic systems?" But "health" extends beyond purely human considerations. We are responsible for the changes we force on the environment, changes that affect water quality, habitat for flora and fauna, and geological stability. How far is the planned septic system from the wetlands on the property next door? Is the site stable, or is it so steeply sloped that any vegetative changes will exacerbate erosion and sedimentation in nearby streams?

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Definition of Land Stewardship

Taken together, we see that the term "land development" does not completely embrace the breadth of activities included in this area of surveying practice and the related body of knowledge. Instead, "land stewardship" better addresses the determination of appropriate use of land with consideration for more than just immediate human gratification. The definition of the functions of a surveyor promulgated by the International Federation of Surveyors (2004) includes the following tasks:

8. The study of the natural and social environment, the measurement of land and marine

resources, and the use of such data in the planning of development in urban, rural, and regional areas.

9. The planning, development, and redevelopment of property, whether urban or rural and whether land or buildings.
10. The assessment of value and the management of property, whether urban or rural and whether land or buildings.
11. The planning, measurement, and management of construction works, including the estimation of costs.

    In the application of the foregoing activities surveyors take into account the relevant legal, economic, environmental, and social aspects affecting each project.

These professional functions, which include land use, site development, and resource management in the natural and social environment, are best described collectively as "land stewardship."

Rationale

Surveyors are the individuals most familiar with the physical characteristics and dimensions of sites slated for development, redevelopment, or preservation. This uniquely prepares surveyors to assist their clients in pursuit of their planned land uses. But such first-hand knowledge of a site is not the only consideration in providing professional services.

Legal, technical, and design variables affect each and every plan for land use and resource management. The natural and manmade environments must interact in a manner that is sustainable for both, and a surveyor's familiarity with site assessment concepts, coupled with first-hand experience of a site, places this professional in a unique position to further such a goal. Part of the process includes preparing reports, plans, descriptions, and exhibits for governmental approval, requiring familiarity with laws and regulations. Another part of the process includes measurement of topography and location of physical features, requiring knowledge of natural and possible legal restrictions affecting a proposed land use.

The land stewardship body of knowledge prepares surveyors to serve their clients and protect the natural environment simultaneously. It is a surveyor's ability to measure, to locate, and to describe physical conditions that qualifies this professional to fulfill such a dual role.

The Surveying Land Stewardship Body of Knowledge

The depth of understanding necessary for various undertakings varies widely, and not every surveyor will need the same level of expertise in every area of the knowledge associated with land stewardship. However, a basic set of skills and knowledge is necessary for surveyors to provide fully rounded, professional land management services. These can be grouped into the following general knowledge areas:

- Communication skills, both written and oral;
- Site design and resource management;
- Site constraints and assets; and
- Project organization, management, and administration.

Within each of these areas, three levels of knowledge and competence depth will be tabulated in Table 1 for general practitioners, specialists, and scholars as follows: "R" for recognition, or reasonable familiarity with a concept or skill area; "U" for understanding, or having a thorough comprehension of a concept or topic; and "A" for ability, indicating a high level of competence.

Knowledge Area: Communication Skills

Although the technical aspects of a project may appear to nonpractitioners to be more critical to the success of the undertaking, without a high level of communications skills, both written and verbal, surveyors cannot even begin to undertake any task at a professional level. Surveyors (and other professionals) must be able to understand what they hear and/or read, analyze the information, and respond appropriately. The so-called "soft" skills of listening and human interaction are a crucial part of professional accomplishment and advancement. Often the presentation of facts is as important as the facts themselves.

1. Core Unit: Analytical Skills

Surveyors must understand what they read and what they hear, to discern the important facts and issues from the background "noise", to parse incoming information, and to pull the critical information from the greater quantity of irrelevant material. They must also ask appropriate questions to ensure they have full understanding of a project or situation. What is being requested and why? The answers guide a surveyor to better serve the client, the public, and the environment.

Area/Core Unit	Core	Specialist	Scholar/R&D
Knowledge Area: Communication Skills			
1. Analytical skills			
Situational analysis	A	A	A
Logic	A	A	A
Objective reasoning	A	A	A
2. Oral expressive skills			
Clarity of expression	A	A	A
Command of language	U	A	A
Physical presentation	R	A	U
Ability to adapt explanations	R	A	U
3. Writing skills			
Clarity of expression	A	A	A
Command of language	U	A	A
Presentation skills	R	A	A
4. Soft or "people" skills			
Listening skills	U	A	U
Negotiation skills	R	A	U
Ability to engage in reasoned debate	R	A	A
Knowledge Area: Site Design and Resource Management			
1. Development design, patterns, and principles			
Identify of existing balance of human and environmental factors	R	U	A
Evaluation of present and future general site context, physical relationship between site and adjacent land, human cultural data, and environmental data	R	R	A
Familiarity with existing and evolving development patterns	R	U	U
Incorporation of sustainability principles into site design and development	R	R	A
2. Land use development and management programs			
Identification of a given site's resources	U	U	A
Familiarity with concept of sustainability	R	R	A
Familiarity with different approaches to preserve various resources during site development	R	R	A
3. Immediate and cumulative effects of site design			
Immediate and cumulative impacts of development on humans and nature	R	U	A
Interdependence of humans and the natural world	R	U	A
Limitations of design	U	U	A
4. Legal requirements for site development			
Federal laws and regulations affecting site development	R/U	A	U
State laws and regulations affecting site development	R/U	A	U
Local ordinances affecting site development	U	A	R
Interrelationship of legal requirements	R	A	A
Knowledge Area: Site Constraints			
1. Assess site suitability for a given plan or design			
Familiarity with the concept of natural and societal resources	U	U	A
Ability to identify and objectively evaluate a specific site's resources	U	U	A
Ability to match site resources, including location, to an appropriate design	R	R	U
Recognition of legal guidelines and restrictions	U	A	U
2. Balancing legal and natural land use restrictions and resource management			
Identification of potential specific impacts (positive and negative) from proposed development	U	U	A
Ability to evaluate changes in natural values and human values (positive and negative) resulting from development, in relation both to the site and to the larger community	R	U	A

R = recognition; U = understanding; A = ability.

Table 1. Summary table.

Area/Core Unit	Core	Specialist	Scholar/R&D
Knowledge Area: Project Administration, Management, and Organization			
1. Project administration			
Contractual responsibilities	U	A	R
Legal responsibilities	R	U	R
Professional responsibilities	R	A	R
2. Project organization and supervision			
Estimation of time, staffing, equipment, and materials needed	U	A	R
Project phasing and scheduling	R	A	R
Time management	U	A	U
Staff supervision	R	A	R
3. Project management (technology and procedures)			
Principles of measurement, imaging, and positioning	U	A	A
Assessment of a project's technical needs	U	A	U
Assessment of project's procedural requirements, including timing	R	A	R
Identification of strengths and weaknesses of various technical approaches in seeking the most appropriate one or combination	R	A	A
Assessment of staffing abilities and needs	R	A	R

Table 1. *(Continued).*

Strong analytical skills are an imperative for the surveyor. The arena of land use, site development, and resource management likely plays a major role in the career of a surveyor, whether a project entails construction stakeout, boundary retracement, wetland location, or clearing for a recreational horseback riding trail. The surveyor must ensure that a full set of information on which to base actions and decisions is available, and must be able to recognize gaps or conflicting information. Logic and objective view are critical to this endeavor, as is understanding various approaches to any given set of conditions and weighing them carefully against each other to derive the best balance.

As just one example: To respond suitably and thoroughly to Requests for Qualifications (RFQs) and Requests for Proposals (RFPs), the surveyor must have a clear understanding of the requested information and the full scope of the proposed project. The surveyor must be able to focus on the stated needs and make no assumptions about what the requestor knows or understands. The surveyor must identify where the document is unclear and then inquire for direct clarification before submitting a formal response to the request. Although supplying answers inappropriate to the requestor's needs may be the result of a poorly written RFQ or RFP, it is more often careless reading of the documents (although possibly in combination with poor writing skills) that is the cause.

Topics or skills in this core unit include the following:

- Situational analysis – includes attention to details of written and verbal information
- Logic – ability to discern relationships and patterns, to order thoughts rationally
- Objective reasoning – ability to remain impartial, make bias-free decisions based on facts

2. Core Unit: Oral Expressive Skills

The surveyor must interact with a wide audience, from the layperson to similarly experienced colleagues, experts in allied fields, and public officials (including staff or commission members). Whether keeping a client informed of changes in site or work conditions, explaining a site plan at a planning or zoning board hearing, or testifying in court as an expert, the surveyor must have a strong command of language and presentation skills.

Topics or skills in this core unit include the following:

- Clarity of expression – organization of thoughts, appropriate level of sophistication of expression to match the audience, appropriate choice of words for a given audience
- Command of language – grammar, impact of chosen words, correct usage of words
- Physical presentation skills – appropriate vocal tone, ability to project voice, ability to speak clearly and calmly, ability to express confidence without arrogance
- Ability to adapt, to explain a concept in multiple ways to reach more of a given audience, and to assure the audience (whether comprised of one person or many) understands the message as intended at whatever level of sophistication is required.

3. Core Unit: Writing Skills

Written expressive skills are similar to oral skills, merely employing a different medium. The wide range of written documents that the surveyor must prepare means that the surveyor must be flexible and capable of utilizing language appropriately and organizing documents in a manner accessible to the intended audience. The surveyor must be able to write contracts (and modify the client's proffered contract to avoid accepting undue liability), respond to a wide variety of requests for information, prepare written real property descriptions, create survey reports, and compose RFQ and RFP documents for work needed from subcontractors when a broader set of skills and expertise is needed.

Topics or skills in this core unit include the following:

- Clarity of expression – organization of thoughts, word choice
- Command of language – clear, complete, sophisticated language appropriate to the intended audience. This includes spelling, punctuation, and grammar skills.
- Presentation skills – tone, organization, style, level of formality

4. Core Unit: Soft or "People" Skills

A professional must be able to hear without judging, to listen respectfully, and respond in an appropriate and reasoned manner regardless of the circumstances. Not unlike the boundary determination process, the surveyor must be able to balance multiple and often conflicting viewpoints of the same issue, whether negotiating fees and scope of service for a contract or requesting access to a restricted site to extend boundary retracement reconnaissance and search activities. Rarely are surveyors contracted if there is not an issue at hand or a need for particular expertise. These situations require not only the ability to recognize what is needed but also the skill to sell the solution. The surveyor must be able to deal with frustrated clients for whom projects do not seem to be moving quickly enough, or explain to zoning boards and audiences at public hearings how the nuances of the proposed project will or will not impact the neighborhood and the protective purposes of land use regulations and ordinances.

Topics or skills in this core unit include the following:

- Listening skills to discern what is being said through the veil of emotions of both the speaker and the listener
- Negotiation skills for resolving differences of opinion
- Ability to engage in reasoned debate

Knowledge Area: Site Design and Resource Management

Undertaking a project involving site development requires an evolving knowledge base. Development concepts and land management programs continue to change as preferences for different development density change and society becomes more aware of the human impact on Earth. Technical and legal knowledge must be supplemented by an awareness of how a plan will affect the area surrounding the project, often encompassing cumulative effects on the immediately adjacent lands and the entire watershed, both above and below ground, while also understanding its effects on economic values. Those physically in contact with the Earth and its resources have the most knowledge to contribute to the development process; surveyors often fill this role.

1. Core Unit: Development Design, Patterns, and Principles

The surveyor is generally the professional responsible for calculating the greatest yield of units in residential development or establishing the geometric layout of parking in commercial areas. This critical phase in the design and development process cannot proceed without the surveyor's participation and input. For these reasons, the surveyor should be familiar with the principles of all development concepts.

Aside from edifices, street design also plays a role in successful site development, encompassing geometry, safety considerations (traffic calming construction such as circles or narrow streets), and the effects of shared routes (bicycle lanes and bus lanes in addition to the traditional family cars). Rerouting design is often accomplished in the field with surveyor's supervision, therefore requiring knowledge of the development process and its impact. Street design, transportation routing, and traffic impacts all affect the quality of the completed project.

Site and development design is more than technical arrangements of structures, lot lines, roads, and utilities. Beyond the layout of functional systems in two-dimensional space, design includes the total environment, not just built and natural forms, but also the three-dimensional spaces around them. Each community will establish its own design objectives that the surveyor must be familiar with in order to best accomplish them. Beyond the layout of the immediate site, there are considerations for the community at large, including open space, circulation patterns, habitat protection, and effect on the larger community. Single-family residential layouts may be the development pattern most familiar to surveyors, but examples of other patterns to consider include mixed-use development, transit-oriented development, clustering, planned unit development, and infill. Surveyors should recognize the principles of New Urbanism, coving, and other development and planning patterns as these evolve.

The existing balance of human and environmental factors must be examined for changes that will occur as a result of the planned development. Present and future balances of these factors must be evaluated in terms of site context (i.e., land-use patterns and circulation systems, population characteristics, ecological and hydrographic systems, area economy, and effects of nearby projects on the site in question), physical data regarding site and adjacent land, human cultural data, and environmental data. Land stewardship requires consideration of more than the economics of development and incorporates "good neighbor" policies, taking into account both human and environmental factors during decision-making.

True stewardship requires us to look beyond the confines of a particular project in evaluating effects of human-induced changes. Sustainable design includes recognition of context, treatment of landscapes as interdependent and interconnected, integration of native landscapes with development, promotion and protection of biodiversity, reuse of already disturbed areas, and inclusion of site repair and restoration in the design process (National Park Service 1993).

Topics or skills in this core unit include the following:

- Ability to identify the existing balance of human and environmental factors
- Evaluation of present and future general site context, physical relationship between site and adjacent land, human cultural data, and environmental data
- Familiarity with existing and evolving development patterns
- Incorporation of sustainability principles into site design and development

2. Core Unit: Land Use Development and Management Programs

For decades we have valued habitat for cars (in the form of streets and parking lots) above habitat for people (lot development) and far above habitat for nature (conservation of natural areas). Such an outlook is changing as we recognize the need for more sustainable use of our finite resources, one of those being land.

Anyone involved with land and resource management must be familiar with the evolving approaches to these undertakings. We must recognize that "resources" include existing structures and consider floodplains and wetlands as amenities rather than obstacles. The following list identifies current programs and the surveyor's level of involvement. This list exemplifies the current state of the art, which continues to evolve along with societal changes.

- Smart Growth – how to make proposed development comply
- Leadership in Energy and Environmental Design Certification (LEED) – understand levels of certification, compliance factors
- Brownfield redevelopment – environmental safety, regulatory issues
- Historic, architectural, and archaeological protection and preservation – (resource management) protective regulations, private client requirements, compliance and documentation processes
- Solar, geothermal, and wind technology applications – site assessment, regulatory issues not limited to compliance and documentation processes
- Mitigation banking – familiarity with principles of land banking, assessment of site suitability for land that will be restored, established, enhanced, or preserved as offsets for wetland or other environmental resource benefits

Topics or skills in this core unit include the following:

- Identification of a given site's resources
- Familiarity with concept of sustainability
- Familiarity with different approaches to preserve various resources during site development

3. Core Unit: Immediate and Cumulative Effects of Site Design

Beyond simple geometry and formulae for site design there are also the social and physical implications of a project, elements with which the surveyor should have at least a passing familiarity. Many of these effects are cumulative in nature, so that a small change here and another one there will result in a much larger end change in the nature of the area. Such effects can occur above, on, and below the Earth's surface, such as the addition of impervious surfaces within a watershed. Hydrological rerouting at micro and macro levels can cause significant changes to patterns of surface runoff, increasing erosion and flooding, saturating soils, and destabilizing foundations elsewhere within the watershed.

Site design must accommodate the natural landscape, taking into account existing water bodies and the disruption of habitat corridors. It must acknowledge that the impact of change does not end at the project's boundaries but instead ripples through society and the environment. The surveyor involved with design and layout must look to the future effects in defending a project at the public hearings integral to the democratic process of community involvement. Therefore, a surveyor should be knowledgeable of, and conversant with, the following aspects of site changes:

- Societal effects (walkable communities, inconsistent land use, social justice)
- Transportation routes (increased traffic, increased traffic speed, access for emergency vehicles)
- Storm drainage design
- Stormwater management design
- Grading and earthwork
- Wastewater and sewage collection and treatment (public and private)
- Water distribution (public and private)
- Stream protection and restoration
- Utility installation and protection
- Soil stability, permeability
- Siltation prevention

Topics or skills in this core unit include the following:

- Immediate and cumulative impacts of development on humans and nature
- Interdependence of humans and the natural world
- Limitations of design

4. Core Unit: Legal Requirements for Site Development

Depending on the jurisdiction and the scope of the project, there may be multiple layers of regulation and review the surveyor must be prepared to address. Most state surveying regulatory boards specifically express requirements that surveyors are to be cognitive of all state and local statutes that apply to professional land surveying. In some instances there may also be federal regulations to address. At the local level, the surveyor must know where to find and how to comply with ordinances addressing a variety of aspects of the planned site development. The process of applying for plan approval involves learning how a particular jurisdiction views certain kinds of site development or resource management projects. The circumstances under which variances will be considered and granted may differ vastly between jurisdictions, as may decisions about when and how subdivision regulations are applied.

There is a wide range of federal, state, and local regulation with which the surveyor must be familiar, both in the application and approval processes. For example (not an exhaustive list):

- Zoning ordinances and processes
- Site plan regulations and reviews
- Inland wetland regulations
- Public Trust Doctrine
- Protection of navigability of various waters
- Coastal zone management regulations
- Program regulations and requirements (U.S. Department of Housing and Urban Development, Federal Housing Administration, etc.)
- Health ordinances
- Building codes, permitting processes, and Certificates of Occupancy
- Subdivision ordinances and processes
- Moratoria on construction or urban sprawl

Regulation of site development is not fully defined by local requirements. Instead, intertwined local, state, and federal regulations mean that the surveyor must have an expanded knowledge of all relevant regulations. At each level of government, there may be stormwater management, floodplain management, habitat preservation, air quality requirements, and other regulations that must be met. The surveyor must be able to locate the guidance documents, understand them, and respond appropriately.

Topics or skills in this core unit include the following:

- Federal laws and regulations affecting site development
- State laws and regulations affecting site development
- Local ordinances affecting site development
- Interrelationship of legal requirements

Knowledge Area: Site Constraints

The surveyor, as the individual on the ground in the development process, must understand the site's physical and environmental constraints so as to assess the feasibility of the project on that site. In particular, as the project moves forward, the surveyor must be able to correctly identify the legal and regulatory constraints associated with the site's specific location and development.

Anyone involved with site development must understand "how things work" in the natural world and be able to balance the constraints of a site with sound resource management. Beyond serving as manager and ambassador of a site development, the surveyor is also the sustainability officer for the project.

1. Core Unit: Assess Site Suitability for a Given Plan or Design

A plan may look good on paper, particularly in terms of benefit/cost ratio, but the particular site may not support the plan as conceived. The following is an abbreviated and non-exhaustive list of aspects to be taken into consideration when determining if a plan suits a site, whether for resource management or development purposes. Although it addresses many of the same topics identified in prior discussion of immediate and cumulative effects, the presently discussed process treats the project as an isolated undertaking.

Here we consider the ultimate question: *Is the site uniquely suited to the proposed project?* The phrase *uniquely suited* indicates a balance between development values and sustainability of resources that benefits human and ecological existence and causes no harm. Each of the site's resources must be evaluated, along with impact on the community. Such considerations include but are not limited to the following:

- Soils – stability (erosion, ability to hold weight of structure), drainage (stormwater concerns, percolation for septic systems)
- Topography – steep slopes, drainage, erosion, low-lying and flood-prone areas
- Water table – height of water table during different seasons, intervening soils and their hydric qualities
- Vegetation – tree cover, vegetated riparian buffers, existing and proposed plantings
- Wildlife habitats
- Mineral deposits or formations (karst/limestone, mines, etc.)—stability, protection, prior claims
- Environmental sensitivity – habitat preservation, wetlands, floodplains
- Transportation – pedestrian or vehicular? Existing and future traffic flow, traffic volume, vehicular access to all areas or restricted access
- Zoning compliance – will variances be required? If so, how many and what impact will they have on the natural and human communities?
- Sustainability of the project in human and ecological terms

Topics or skills in this core unit include the following:

- Familiarity with the concept of natural and societal resources
- Ability to identify and objectively evaluate a specific site's resources
- Ability to match site resources, including location, to an appropriate design
- Recognition of legal guidelines and restrictions

2. Core Unit: Balancing Legal and Natural Land Use Restrictions and Resource Management

There is interplay between what the laws and regulations technically allow and what is sound resource management. We must follow both the letter of the law and the spirit of the law to accomplish true land stewardship, protecting both the landscape and society. We must balance natural land use restrictions with regulatory land use restrictions. The result of this consideration may lead to adoption of alternative plans or abandonment of plans when no equitable balance can be achieved. The surveyor's professional opinion can benefit the public and the project regarding pursuit or avoidance of requesting variances from laws and regulations. A sound approach to design must recognize the impacts of every design choice on the natural and cultural resources of the local, regional, and global environments.

Topics or skills in this core unit include the following:

- Identification of potential specific impacts (positive and negative) from proposed development
- Ability to evaluate changes in natural values and human values (positive and negative) resulting from development, in relation both to the site and to the larger community

Knowledge Area: Project Administration, Management, and Organization

Surveyors undertaking land use, site development, and resource management projects must be well organized and must be wise managers and administrators. They must have broad understanding of appropriate technology and procedures required for site development, thus maintaining a "big picture" view of the project, and be able to understand the phasing of the various components of a land development project. Surveyors must also be able to zoom in on the details to ensure that the appropriate procedures are employed to reach the desired end result. Scheduling requires an understanding of all the steps involved and of the technology selected to complete certain processes. Familiarity with project administration, management, and organization enables the professional to reserve and conserve resources over a project's lifetime.

1. Core Unit: Project Administration

High on the list of administrative abilities relating to this topic is comprehensive legal knowledge of business practice as it relates to site development. Prior to undertaking any project, a surveyor must fully understand a contract's scope and terms, the law that upholds the enforceability of the contract to the benefit and/or detriment of the parties to that document, and the effect of the terms and conditions of a contract on the professional responsibilities of the surveyor. All too often a failure to understand those terms and conditions can lead to an exposure to liability beyond the professional responsibilities of a surveyor. In addition to being well versed in professional liability, rules of evidence, and surveying regulations, the surveyor should be cognizant of other business laws, such as those requiring the use of protective gear or special training for employees on various sites and identifying when prevailing wages must be paid. The professional must also fully understand the statutes and regulations affecting environmental protection and site development to assess impacts on the business of planning and completing a project as required by law pertaining to that project and as part of the surveyor's professional responsibility. For example: Will workers be required to hold HazMat certification to survey a former toxic dump site? What rules will guide when there is a conflict between the parties? What can be communicated between clients, contractors, and subcontractors about a project or status?

Topics or skills in this core unit include the following:

- Contractual responsibilities
- Legal responsibilities
- Professional responsibilities

2. Core Unit: Project Organization and Supervision

The contract should define the project's parameters, the responsibilities and duties of the parties, and how the project will be accomplished in general terms, but then the surveyor must address how a project will proceed more specifically. This entails establishing phases of the activities to be performed, identifying the sequence of activities, the coordination of activities, and when deliverables are to reach the client and in what format. In the process of compiling cost estimates for a proposal, the surveyor must estimate time and materials required, time frames, and scheduling limitations (for example, constraints related to external approvals). The various steps entailed in completing a project are examined as to the length of time necessary for each project activity, their sequence, and whether they are planned to be concurrent or sequential, with or without overlaps.

Once winning a contract, the surveyor may coordinate the local approval processes and may possibly record documents for final completion and acceptance by the regulating bodies. Appropriate staffing must be available to complete the various phases or aspects of the project, and scheduling of site visits and meeting presentations must be planned to ensure that there are no overlaps or gaps in who is supposed to be where and when. Careful oversight of the project and a high level of organizational skill are necessary for a project to succeed on time and on or under budget.

When fulfilling the contract's requirements and deliverables, the surveyor must avoid cost overruns, errors, and damages. Simultaneously, professional ethics demand protection of both people and the site when such need becomes apparent.

Topics or skills in this core unit include the following:

- Estimation of time, staffing, equipment, and materials needed
- Project phasing and scheduling
- Time management
- Staff supervision

3. Core Unit: Project Management (Technology and Procedures)

The surveyor must be able to assess the necessary level of accuracy for any given project. This requires familiarity with available technology and procedures to implement the most suitable and practical approach. The professional assessment may entail evaluating the differences between machine control stakeout and more traditional ground methods, establishing whether a new boundary survey of the site is needed or, if one is provided by the client, whether it will suffice, and determining whether available photogrammetry provides adequate topographical detail or if new imagery is necessary. Is information gleaned from a geographic information system adequately detailed and accurate to provide a sound basis for planning? Does the client need digital files in a particular format (possibly an outdated version)?

At every step, the surveyor must evaluate various procedures and available technology in terms of the accuracy desired for the project, time to implement (including any necessary training), adequacy of skills held by available staff and possible subcontractors, and appropriate medium for the delivery of final reports and other documents. The surveyor must therefore maintain current knowledge of, and familiarity with, a range of technological advances to formulate an effective and efficient plan to manage the project from start to finish.

The surveyor must not work beyond his or her expertise in applying technology and procedures. Where the skills are lacking, ethics demand that the surveyor must seek external support to ensure a proper professional product is produced.

Topics or skills in this core unit include the following:

- Principles of measurement, imaging, and positioning
- Assessment of a project's technical needs
- Assessment of project's procedural requirements, including timing
- Identification of strengths and weaknesses of various technical approaches in seeking the most appropriate one or combination
- Assessment of staffing abilities and needs

Concluding Remarks

Land stewardship encompasses protection of the natural and human environments, and the surveyor involved in this professional arena must be familiar with the context of any particular plan for land use, land development, or resource management. Site assessment and site planning are not merely exercises in economics, but they must be part of a calling to a higher standard of ecological soundness and community benefit. Integrating business skills, communication skills, and legal knowledge best protects the public's welfare in pursuing sustainable development and results in a successful project.

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