Relationship between Systems Engineering and Geospatial/Geodetic Engineering

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This article discusses the relationship between Systems Engineering (SE) and Geospatial/Geodetic Engineering (GGE) as reflected through relationships between several Specialty Engineering disciplines listed in INCOSE (2015) and GGE. For most of these disciplines, there are also SEBoK articles in the Knowledge Area SE and Quality Attributes.

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Geospatial Aspects in the INCOSE Specialty Engineering Activities

Systems that directly include geospatial components and system elements, or that perform navigation operations or deal with referenceable objects in their broadest interpretations require dedicated contributions from the geodetic/geospatial domain. Those contributions should be achieved by integrating appropriate subject matter experts into SE teams.

The following sections briefly describe possible geospatial solutions or contributions which may directly support some of the Specialty Engineering activities in INCOSE (2015).

Environmental Engineering/Impact Analysis

Analyzing a spatial distribution or dispersal of pollutants typically depends on specific modules that have been integrated into Geographic Information Systems (GIS); e.g. a plume modeler will estimate how chemicals dissolve in the atmosphere under certain meteorological conditions. Other applications determine run-off for flooding simulations, or reveal dependencies between different types of environmental parameters during geospatial analysis. The list of such applications is long. The Knowledge Area (KA) Systems Engineering and Environmental Engineering provides more information.

Interoperability Analysis

Interoperability has been a major issue in geospatial infrastructures for decades. The Open Geospatial Consortium (OGC), founded in 1994, published its first standard (OpenGIS Simple Features Specification) in 1997. Other organizations also publish standards including the International Organization for Standards (ISO) with its Technical Committee 211 Geographic information/Geomatics (see also here), the International Hydrographic Organization (IHO) and the North Atlantic Treaty Organization (NATO). For meteorological data, the World Meteorological Organization (WMO) standardizes respective services and data formats.

Typically, these bodies closely cooperate.

Using these standards can lead to significant cost savings in the development and operation of systems and thus contributes to another INCOSE Specialty Engineering activity: Affordability/Cost-Effectiveness/Life Cycle Cost Analysis. NASA funded a study that was conducted by Booz Allen Hamilton (2005). The study found that the project that adopted and implemented geospatial interoperability standards:

- had a risk-adjusted Return on Investment (ROI) of 119.0%. This ROI is a "Savings to Investment" ratio over the 5-year project life cycle.
- had a risk-adjusted Return on Investment (ROI) of 163.0% over a 10-year period.
- saved 26.2% compared to the project that relied upon proprietary standards.

Another finding was that standards-based projects have lower maintenance and operations costs than those relying exclusively on proprietary products for data exchange.

As a general conclusion from the above, there are substantial contributions from the geospatial domain that support interoperability analyses.

Logistics Engineering

According to INCOSE (2015), "Logistics engineering ... is the engineering discipline concerned with the identification, acquisition, procurement, and provisioning of all support resources required to sustain operation and maintenance of a system." Amongst others, the following elements supporting logistics engineering are identified in INCOSE (2015) that have a direct relation to geospatial, GIS and PNT/Global Navigation Satellite Systems (GNSS) technologies:

- Sustaining engineering;
- Training and training support;
- Supply support;
- Facilities and infrastructures; and
- Packaging, handling, storage, and transportation (PHS&T).

Typical keywords associated with related activities are:

- "Technical surveillance" where, e.g., fielded systems are monitored with means of geodetic engineering techniques, such as deformation analysis of structures and sites,
- "Simulation" that requires virtual 3D environments and GIS,
- "Facilities" that are nowadays managed with Building Information Modeling (BIM) techniques which have a close connection to GIS, based on cadastre data from local authorities,
- "Transfer" and "transportation" where objects, material and goods are moved in space involving amongst others GIS with navigable map used for planning routes and navigation during transport.

Sometimes, GNSS and real-time GIS technologies are also used for tracking cargo of interest for safety reasons.

Reliability, Availability, and Maintainability

How reliable is a map, or, in the digitized world, a geographic data set displayed on screen or a mobile device? That depends firstly on the source of data, i.e. how reliable the source is, and on the other hand even for trusted data sources on the need to update that data set according to operational requirements and the changes that take place in the landscape of the area of interest. Updating and otherwise maintaining geospatial databases is a costly and sometimes time-consuming operation (again tied to the Specialty Engineering activity "Affordability/Cost-Effectiveness/Life Cycle Cost Analysis"). Efficiently updating geospatial databases is discussed from a technical perspective in Peters (2012) and, at least to a certain extent, must be reflected as well in the design of a geospatial data infrastructure. Using central services to provision geographic data is one possibility to address this issue since then, only one data set needs to be updated according to the single source of information principle. Others will access this data set via services to always receive the latest version of available data. The required availability constraints clearly must be addressed in the design of the IT infrastructure that hosts such a geospatial database, and also IT security aspects need to be considered.

Resilience Engineering

In recent years there has been an increasing awareness of the vulnerabilities of systems depending on GPS/GNSS. Resilient PNT is heavily discussed and alternatives like eLoran and Satelles are often mentioned in this context. According to the Royal Academy of Engineering (2013), "all critical infrastructure and safety critical systems that require accurate GNSS derived time and or timing should be specified to operate with holdover technology for up to three days." This source also lists other recommendations to be considered for system design.

A source that provides example cases on a regular basis is the Resilient Navigation and Timing Foundation (RNT Foundation). Examples of official reports in the US and the UK are also Wallischeck (2016) and Royal Academy of Engineering (2011). Jamming and GPS disruptions actually occur and sometimes official warnings are issued, e.g. by the US Coast Guard (DHS 2016). According to an RNT Foundation notice, there was an official warning from flight authorities during the 2017 G20 event in Hamburg, Germany. It cautioned to consider the possibility of GPS disruptions caused by intentionally initiated activities and actions to protect the G20 conference.

Prudent systems engineers will consider such dependencies and ensure to the degree practical that the systems at hand are resilient and fault tolerant, i.e. those systems do not terminate safe and reliable operation in the absence of GNSS signals, or cause major problems when they need to continue to communicate with other systems.

System Safety Engineering

Although it may not be straightforward, even in System Safety Engineering there are aspects that may be supported by geodetic and surveying engineering. One example may be the monitoring of dams, bridges and buildings etc., i.e. to what extent constructions move under differing environmental conditions, especially when subject to wind or water pressure or heat. Another example is the monitoring of natural objects such as volcanoes or slopes to detect early the possibility of future volcanic eruptions or potential landslides, or the monitoring of fracture zones or areas prone to earthquakes.

Usability Analysis/Human Systems Integration

Geographical displays sometimes form a central part of user interfaces. In such cases, proper usability analysis and other aspects of Human Systems Integration (all of these activities are part of Human Factors Engineering, HFE), geospatial expertise may be required. But beyond this, in HFE several other aspects are considered covering the general interaction of users with systems (Stanton et al. 2013). Nevertheless, in displaying virtual environments, HFE is related to the science and application of cartography (Kraak and Ormeling 2020) because the latter deals not only with portrayal of geographic data but also heavily with the different ways of human perception and abstraction of spatial phenomena, especially in dependence of the different scales the data is displayed.

Geospatial Aspects in Modeling and Simulation

Modeling and simulation is a broad field and heavily used in various disciplines and as such also in different SE life cycle processes. Geospatial technologies contribute to these activities amongst others by providing geographic data to create realistic environments, either for 2- or 3-dimensional applications. According to INCOSE (2015), such a model is then termed a "formal geometric model". When considering temporal aspects and phenomena as well, 4-dimensional models are used. The modeler has to discern what types of geographic information must being modeled, and whether they are discrete objects which can be delimited with boundaries or whether they are continuous fields representing "the real world as a finite number of variables, each one defined at every possible position" (Longley et al. 2015), like temperature. For a comprehensive introduction to the general theory of geographic representation in GIS with continuous fields and discrete objects and how these concepts may be integrated see Longley et al. (2015), Goodchild et al. (2007) and Worboys and Duckham (2004).

In traditional cartography a map model was described by the well-known map legend that explained the portrayal of depicted features or phenomena. Today, fairly straightforward models for perspective visualization of landscapes are created using so-called Digital Terrain Models (DTM) and rendering them with geographic

imagery. With these types of models no further descriptive information may be extracted besides geometric information and visual interpretation of the imagery to decide what is actually there. A well-known application for this is Google Earth. Vector models can provide more information. Discrete objects in a vector model may be further described by attributes, e.g. the width of a street. Vector models are created using so-called "feature catalogues" that define which real world objects and domain values are to be represented. A typical military feature catalogue was created by the Defence Geospatial Information Working Group (DGIWG) for worldwide military mapping projects and is called the DGIWG Feature Data Dictionary (DFDD). Feature catalogues vary with different levels of modeling scales, i.e. large-scale models provide a higher granularity than small-scale models that provide more of an overview.

INCOSE (2015) lists the following purposes for models throughout the system life cycle:

- Characterizing an existing system,
- Mission and system concept formulation and evaluation,
- System architecture design and requirements flow-down,
- Support for systems integration and verification,
- Support for training, and
- Knowledge Knowledge capture and system design evolution.

The second and fifth purposes may be supported by geospatial technologies; i.e. data and software components that create, store, simulate and visualize/portray real world or virtual models of environments where a system is going to be deployed, or where operations are going to take place (Tolk 2012). "Mission and system concept formulation and evaluation" tie to the definition of the Concept of Operation (ConOPS). By analyzing different variants of system deployment and categorizing them based on defined cost functions, it is possible to optimize a system design to provide a solid basis for decision making.

Conclusions

Geodetic and geospatial technologies and services play a fundamental role in many systems of systems and stand-

alone systems. The general public is often not aware how strongly their lives and activities depend on these assets to provide and maintain critical infrastructure such as electric power and communications services. Against this background, systems engineers often need mastery of GGE knowledge and access to GGE subject matter experts and as a consequence, Geospatial and Geodetic Engineering may be considered as well a Specialty Engineering Discipline for Systems and Systems of Systems Engineering endeavors.

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Additional References

None.