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Situational Awareness for Biosurveillance

"He who loves practice without theory is like the sailor who boards ship without a rudder and compass and never knows where he may be cast."

Leonardo da Vinci
(1452-1519)

Situational awareness (SA) is one of the two main functions of a biosurveillance system. As Homeland Security Presidential Directive 21 (HSPD-21) states, biosurveillance is "the process of active data-gathering with appropriate analysis and interpretation of biosphere data that might relate to disease activity and threats to human or animal health – whether infectious, toxic, metabolic, or otherwise, and regardless of intentional or natural origin – in order to achieve early warning of health threats, early detection of health events, and *overall situational awareness of disease activity*" [emphasis added] (U.S. Government, 2007).

Intuitively, most interpret the term "situational awareness" to mean that one is cognizant of one's surroundings. But awareness in this sense is actually only one part of situational awareness. A solid understanding of, and rigorous definition of, situational awareness in a biosurveillance context is critical for being able to assess whether a biosurveillance system in fact provides situational awareness, how such systems should be modified to improve biosurveillance situational awareness, and whether one system or method provides better situational awareness and thus should be preferred.

This chapter begins by defining situational awareness and then describing a general theoretical model of situational awareness that has been used in many non-biosurveillance decision making contexts. The chapter discusses how the general model applies to biosurveillance and then connects data and statistical methods to where and how they are required to support situational awareness.

CHAPTER OBJECTIVES

Upon completion of this chapter, you should be able to:

- Define situational awareness, including the three levels of situational awareness: perception, comprehension, and projection.
- Describe why maintaining situational awareness in a dynamically changing environment is important.
- Explain the difference between situational awareness and situation assessment.
- Give examples of how good situational awareness enhances good decision making and how decision making can be degraded with poor situational awareness.
- Apply Endsley's theoretical situational awareness model to biosurveillance.
- In a biosurveillance context, discuss what types of data and/or statistical methods are required to support the three levels of situational awareness.
- Describe how the Situated Cognition Model extends the theoretical situational awareness model and what the implications are for biosurveillance system design.

3.1 What is Situational Awareness?

Situational awareness (SA) is often a critical prerequisite for successful decision making, particularly in complex, dynamically changing situations. Endsley (1995, p. 36) defines situational awareness as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Thus, situational awareness is not only about being aware of the current state of events, but also being able to put those events in the context of what is expected so one can understand what they mean, and it involves being able to understand what is likely to occur in the near future given current events. Endsley (1995) goes on to say that "it is important to distinguish the term situation awareness, as a state of knowledge, from the processes used to achieve that state. These processes, which may vary widely among individuals and contexts, will be referred to as situation assessment or the process of achieving, acquiring, or maintaining SA." Thus, situational awareness is a state of knowledge and situational assessment is the process or processes necessary to achieve SA.

It is important to recognize that achieving situational awareness requires more than having lots of data or information available. In fact, while a lack of information can impede situational awareness, so can excessive, irrelevant, or disorganized information result in the lack or loss of situational awareness. Think about the problem in terms of driving a car in an unfamiliar location and trying to get to a particular destination. If the location is out in a very rural area without street signs then it is pretty easy to get lost due to a lack of information about the roads. On the other hand, if the location is New York City and you are driving through Times Square, it is also easy to get lost due to all the visual distractions, the busy traffic, and other sources of information overload.

Data is not necessarily information and, as Endsley (2001) notes, more data does not necessarily provide more information. Similarly, more information does not necessarily translate into more or better situational awareness. Human beings are limited by nature and experience in terms of how much information we can process, where certain forms of information are easier to process and understand, and internalizing, integrating, and understanding the meaning of information can be made easier or harder depending on how the information is presented. Thus, the challenge of improving situational awareness is one of identifying what information is needed, and when it is needed, within the context of a particular decision making problem or scenario.

Situational awareness has been carefully and deeply studied in a number of contexts. For example, in aviation the focus is on pilots maintaining appropriate situational awareness of the aircraft, including its location in space, whether it's on the correct flight path, its material condition and status, etc. Designing nuclear plant operations consoles is another example, where significant effort has been invested in designing interfaces that help facilitate situational awareness.

3.2 A Theoretical Situational Awareness Model

A well-known theoretical model for SA was defined by Endsley (2001, 1995). It posits three distinct levels of SA: (1) perception of the elements in the environment, (2) comprehension of the current situation, and (3) projection of the future status of the situation. These levels are defined as follows.

- Level 1 SA, *Perception of the elements in the environment*: Discerning the relevant elements in the environment, including their attributes, status, and dynamics, is the most basic level of SA. It is awareness of the elements (which may be objects, events, people, systems, environmental factors) and their current states (e.g., locations, conditions, modes, actions). Thus, Level 1 SA involves not only recognition of the relevant elements, but also on-going monitoring the elements since they may change over time.
- Level 2 SA, *Comprehension of the current situation*: The next level of SA involves a synthesis of the elements in order to comprehend the situation. That is, Level 2 SA requires integrating the information perceived in Level 1 in order to understand significance of the those elements on the desired goals or outcomes. Through the processes of pattern recognition, interpretation, and evaluation, Level 2 SA results in a holistic understanding of the environment that allows for the comprehension of the significance of elements and events.
- Level 3 SA, *Projection of future status of the situation*: The third and highest level of SA involves the ability to project the future status of the elements in the environment. Given perception and comprehension of the situation (Levels 1 and 2 SA), as well as knowledge about how the elements interact dynamically, Level 3 SA is achieved by using this information to project likely future states of the environment that are important or useful for decision making.

What it means to achieve each of these levels is highly context dependent for a given situation or scenario. That is, the information necessary for a pilot to achieve SA is completely different from what is required for a nuclear plant operator, and certainly the information necessary for a public health official to maintain situational awareness during a pandemic is similarly quite different from the other two occupations.

As shown in Figure 3.1, in a dynamically changing environment these three levels of situational awareness are embedded in a loop where the situation is ever changing, both in response to external influences as well as to changes that result from prior decisions that subsequently affect the current state of the situation. That is, changes in the environment can affect situational awareness, sometimes improving it and other times perhaps degrading it. Similarly, the decisions made with some level of situational awareness can make the situation either better or worse, ultimately feeding back upon the decision maker and perhaps affecting his or her situational awareness for the better or worse.

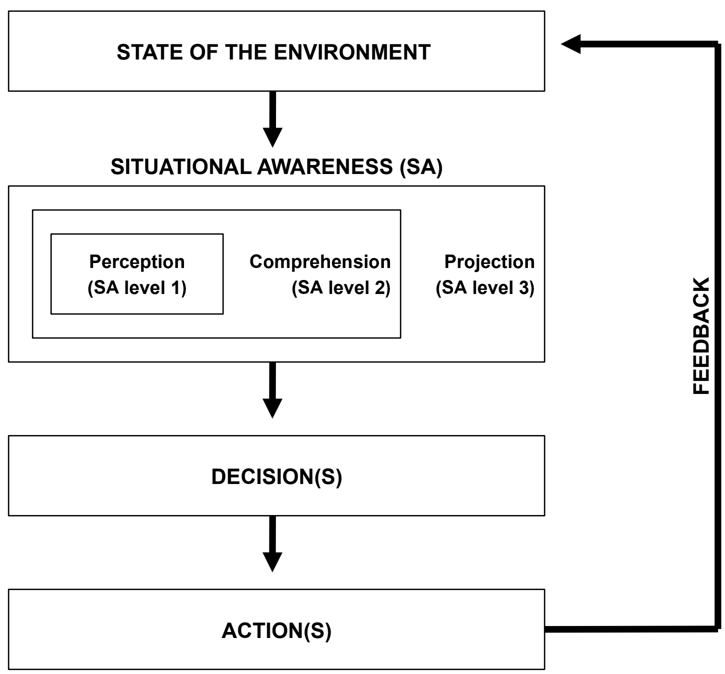

Fig. 3.1. Situational awareness in Endsley's model has three levels: perception, comprehension, and projection. In a dynamic situation, situational awareness is embedded in a loop where the environment affects SA and decisions made under a particular level of SA affect the environment (and hence future SA). Adapted from Endsley (1995).

Returning to the driving example, anyone driving in a large, unfamiliar city has been in the situation where as they're driving they start to lose track of their location – i.e., their situational awareness starts to degrade. To attempt to recover, they make make decisions about where to turn, and those choices either result in getting back on track and thus an improved situational awareness or perhaps getting lost and further degradation of situational awareness. A key idea is that situational awareness is a mental construct of the actual situation. To the extent that the mental construct matches the actual situation good decisions can be made. The more the mental construct departs from the actual situation, the more likely that inappropriate or incorrect decisions will be made.

Of course, these days, one strategy many drivers use to improve situational awareness is a GPS receiver that provides visual maps showing current location and verbal directions about the route to follow. In terms of the three levels of SA, GPS units can improve perception by showing the car's location on a map; it can improve comprehension by displaying the location with respect to the desired route; and, it can improve projection by giving advance notice of future actions the driver will need to take to say on the route.

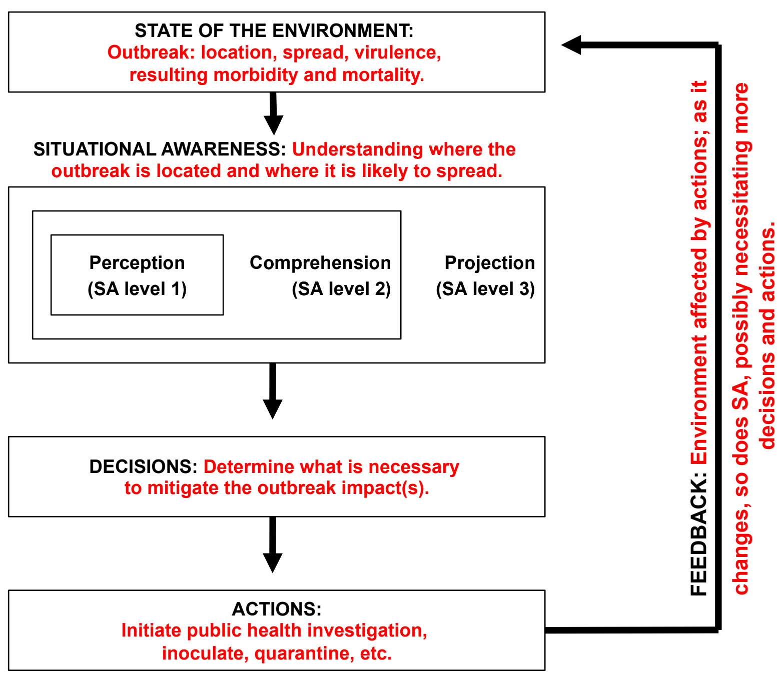

Fig. 3.2. Endsley's model of situational awareness applied to biosurveillance.

In the driving example, note that SA involves both a temporal and a spatial component ("Am I on time?" and "Am I on track?"). The importance of time in situational awareness is important because, in a dynamic situation such as flying a plane or managing the public health response to a pandemic, things are constantly changing. Thus it becomes critical to be able to appropriately update one's mental construct of the situation in response to constantly changing conditions. In terms of biosurveillance, the spatial component is often of importance as well. It's not enough to know when an outbreak is occurring, one must also know where, and one must keep track of the outbreak region or regions as the pandemic evolves over time.

3.3 Biosurveillance Situational Awareness

Figure 3.2 illustrates how Endsley's theoretical model applies to biosurveillance. The environment is the human, zoonotic, or agricultural population of interest, including their heath status, disease vectors, and the status of intervention assets. During an outbreak it includes the location, spread, virulence, and resulting morbidity and mortality of a disease or agent. The situational awareness is what a decision maker (either in terms of a public health individual or an organization) believes they know about the environment. Decisions and their subsequent actions, including initiating epidemiological investigations and public health interventions, then affect the environment and complete the loop.

In terms of the three levels of SA, a recent Government Accountability Office (GAO) reports states,

> "Officials at CDC with key biosurveillance responsibilities subscribe to a definition that includes three components:
>
> 1. awareness that a situation has occurred (e.g., detection of a biological condition that differs from the norm),
> 2. comprehension of its meaning (e.g., characterization of the nature and scope of a biological event), and
> 3. projection of its likely course in the near future (e.g., how its nature and scope will evolve and the decision implications of that evolution, particularly whether it may have catastrophic consequences).
>
> The projection aspect of situational awareness, sometimes overlooked in other definitions, is crucial in the biological context, because of the high degree of uncertainty and instability as the event unfolds over a period of time, which is not necessarily encountered in more discrete disaster events." (GAO, 2010, p. 13)

Thus, at least in broad terms, the application of the Endsley model to biosurveillance problems seems clear. Perception is detection of an event. Comprehension is understanding the event, both in terms of type and scope, as well as the availability of resources to intervene. And, projection is being able to project what will happen in the near future in terms of how the situation is likely to evolve. Note that, according to this definition, early event detection is actually part of situational awareness.

Bolstad *et al.* (2011, Fig. 4.2) also discuss the three levels of SA in terms of the broader biosurveillance problem, where they characterize them in terms of answering questions:

- SA Level 1, Perception: “Which information do I need?”
- SA Level 2, Comprehension: “What does this mean to me?”
- SA Level 3, Projection: “What do I think will happen?”

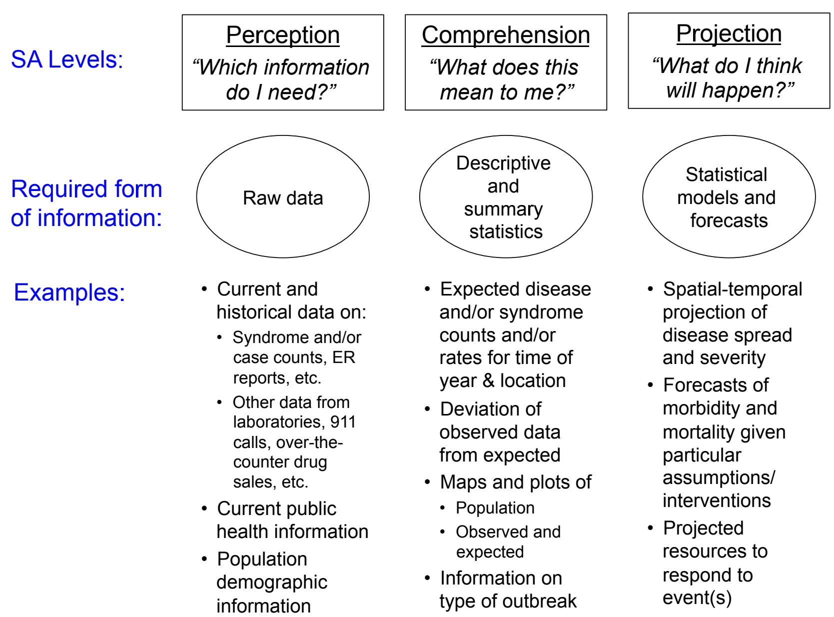

Fig. 3.3. The three levels of situational awareness each depend on specific types of data and statistical methods for their information requirements. Level 1, Perception, depends on the collection of the correct raw data. Level 2, Comprehension, depends on appropriately summarizing the raw data via descriptive and summary statistics. And, Level 3, Projection, depends on the having good statistical models and forecasting methods to project what is likely to happen in the near future. Adapted from (Kass-Hout & Zhang, 2011, Fig. 4.2).

Following this approach, Figure 3.3 puts the three levels of situational awareness in the context of the necessary data and statistical methods. Thus, SA Level 1 is the acquisition of the necessary and appropriate data, which may include current and historical data on syndrome and/or case counts as well as other types of data from laboratories, 911 calls, over-the-counter drug sales, etc., and current population demographic and public health information.

Building on Level 1, SA Level 2 is the application of descriptive and summary statistics and plots to the raw data to facilitate understanding of the data. At this level the goal is to turn the raw data into information that helps a decision maker understand what the current state of affairs is, both in terms of historical norms and whether, how much, and where the existing situation deviates from those norms. Thus, SA Level 2 involves the use of maps and plots to display the expected and observed status of the population, including expected disease and/or syndrome counts and/or rates for time of year and location and the deviation of the observed data from what would be expected.

Finally, SA Level 3 requires the use of statistical models and forecasts to provide a spatial-temporal projection of disease spread and severity along with forecasts of morbidity and mortality given particular assumptions and interventions. In addition to forecasting the disease, other types of forecasts may be required, such as the projected level or amount of resources available to respond to the event(s).

3.4 Extending the Situational Awareness Model: Situated Cognition

Endsley's model is focused on the decision maker and, as presented in Figures 3.1-3.2 implicitly assumes that the decision maker has the necessary, correct, and appropriate data available from which to make decisions. It also does not seem to address the issue that different decision makers may reach different decisions based the their particular situation. Shattuck & Miller's Situated Cognition Model incorporates these real-world situational awareness considerations.

In terms of data, for example, the decision maker can only have a subset of all possible data in the environment and thus it's important to recognize that a decision maker's mental model of the situation will both be limited by unavailable data and shaped by the available data. This includes how the data is parsed and presented, and how it's interpreted by the decision maker. This is an important consideration when designing and operating a biosurveillance system since design and operation directly affect the information available to the decision maker.

As Shattuck & Miller (2006) discuss, one issue is how technology and system design either enhances or degrades information. As shown in Figure 3.4, at the far left (1) is all the data that's available in the environment. Of all this data, not all of it is "detected" in (2), which could mean that it's literally not detected, as in an individual who is sick but only self-medicates and so is not visible to the public health system, or perhaps the biosurveillance system's coverage of the population is incomplete either because some providers are not providing data or perhaps that some types of data are in a convenient electronic form and thus not able to be captured in a biosurveillance database.

Whatever the reason, not all of the data that exists in the environment will be available or in a form that it useful for the biosurveillance system.

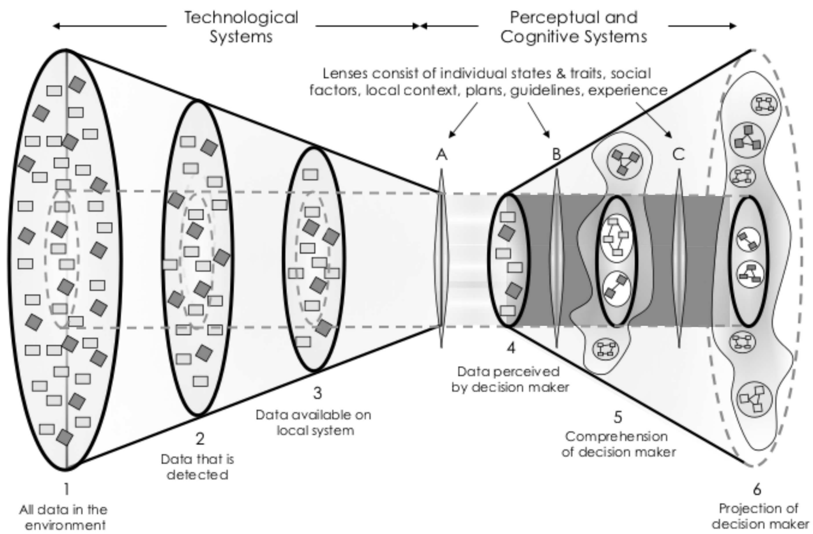

Fig. 3.4. Situational awareness depends not only on how a human being interprets data, but on what data is actually available to be interpreted. The Dynamic Model of Situated Cognition above illustrates that the way data is handled in and filtered through technological systems affects situational awareness. Source: Shattuck & Miller (2006, Fig. 1).

Now, of all the data that's detected, only a subset of that will be available or visible on the local biosurveillance system in (3). For example, choices in how the data is filtered in the system, how the data is processed, including the choice of early event detection algorithms, as well as how the data is displayed (for example, the types of maps and plots available) may reduce the data that can be locally displayed. In addition, depending on the system structure, it may limit access to the raw data, perhaps for privacy reasons, or the ability to sort or conduct *ad hoc* analyses. Thus again, perhaps for a variety of reasons, the data available to the decision maker is reduced from all that exists in the environment.

It should thus be clear that in the real world, system design has the potential to dramatically affect biosurveillance effectiveness. However, decisions are affected by more than system design. In Figure 3.4, Shattuck & Miller

(2006) use a lens metaphor of lenses to illustrate the decision maker's perception, comprehension, and projection (the three SA levels) are shaped by his or her personal experience as well as the local context and response plans and guidelines. Shattuck & Miller refers to these as the "perceptual and cognitive systems." Simply stated, different people with different types of experience, or operating in an environment with different guidelines and requirements, may reach different decisions, even with data that is otherwise the same.

3.5 Discussion & Summary

This chapter discussed situational awareness and described two complimentary theoretical models of situational awareness. A key insight of these models is that there are three levels of situational awareness: perception, comprehension, and projection.

As described in Figure 3.3, the three levels of situational awareness each depend on specific types of data and statistical methods for their information requirements:

- Level 1, Perception, depends on the collection of the correct raw data. In terms of this book, Chapters 1 and 2 described the types of biosurveillance data that are currently being collected. Whether these types of data are "correct" in the sense that they best support situational awareness is an open question.
- Level 2, Comprehension, depends on appropriately summarizing the raw data via descriptive and summary statistics. Descriptive statistical methods useful for situational comprehension will be discussed in the next chapter, Chapter 4.
- Level 3, Projection, depends on the having good statistical models and forecasting methods to project what is likely to happen in the near future, which will be developed in Chapter 5.

The GAO defined biosurveillance situational awareness as "information that signals an event might be occurring, information about what those signals mean, and information about how events will likely unfold in the near future" (GAO, 2010, p. 6). While these three steps follow Endsley's model, clearly biosurveillance is more than just an event-focused activity. Event (i.e., outbreak) detection and tracking is one of the main goals of biosurveillance, but one cannot judge whether an event might be occurring unless one also has situational awareness of the biosphere *prior to the event.* As Rolka *et al.* (2008, p. 2) say,

> "Public health situation awareness is needed by public health leaders in three different types of settings that can occur simultaneously or in sequence: 1) pre-event/threat situations where a wide range of public

> health events and threats are assessed, 2) emergency response situation awareness in which detailed assessments of a specific event or threat and the public health responses to that threat are monitored, and 3) recovery operations during which the on-going mitigation and preventive efforts to a specific event or threat are monitored."

Compared to early event detection, some argue that situational awareness is the more important function because it is something a biosurveillance system needs to continuously support. That is, as just described, it is important to maintain situational awareness of the biosphere whether an outbreak is present or not, while EED is only necessary given an outbreak. However, as described in this chapter, EED is actually a part of Level 1 situational awareness and thus the two cannot be separated.

Some have also argued that EED is more effectively performed by individual medical professionals during the treatment of patients rather than by a statistical algorithm, while SA is inherently better performed by aggregating information across doctors and hospitals, hence within some sort of biosurveillance system. Given this is a book about statistical methods in support of biosurveillance, statistical methods for EED will be developed in Chapters 6-**??**. However, even before discussing the statistical methods for EED, it should be clear that one approach does not rule out the other, and so some appropriate combination of the two approaches is to be preferred over just one or the other.

While not the focus of this book, one thing this chapter should have brought to mind is that biosurveillance system design is critical to acquiring and maintaining situational awareness, particularly in the midst of a major outbreak. Unfortunately, to-date it appears that system designs have been driven more by technology and the convenient availability of certain types of data than by deliberate design in support of biosurveillance situational awareness. As Toner (2009) says,

> "While these surveillance efforts undoubtedly provide information flows that did not exist before, it is not clear to what extent they have enabled a more robust understanding of a rapidly unfolding event. How do, or how can, these diverse systems, programs, and centers work together to provide an integrated picture? Can decision makers use these systems effectively to direct action in a crisis? Do these systems provide the necessary information in real time? It seems overall that there has been much more emphasis placed on systems to detect outbreaks rather than on systems to manage outbreaks. It appears that there is a lot of technology, but relatively little science. Systems exist without a clear concept of operation."

However, the beginnings of change are appearing; situational awareness in the context of system design is starting to be discussed in the literature. See, for example, Bolstad *et al.* (2011) and Toner (2009). However, compared to fields such as aviation, the discussion has barely begun. Furthermore, discussion is not sufficient. Those public health organizations operating biosurveillance systems need to sponsor and support studies of whether and how the systems support situational awareness and facilitate system improvements to enhance their situational awareness functionality.

Additional Reading

While situational awareness is one of the two main foci for biosurveillance systems, surprisingly little has been written about SA in a biosurveillance context. For those who would like to delve more deeply into the material presented in this chapter, consider:

- For more information about Endsley's theoretical model, see the original paper, *Toward a Theory of Situation Awareness in Dynamic Systems* (Endsley, 1995) as well as *Situation Awareness: Analysis and Measurement* (Endsley & Garland, 2000). For a more in-depth discussion of the situated cognition model, see Shattuck and Miller's original paper, *Extending Naturalistic Decision Making to Complex Organizations: A Dynamic Model of Situated Cognition* (Shattuck & Miller, 2006).
- Returning to the issue of designing biosurveillance systems to support situational awareness, Chapter 4 of *Biosurveillance: Methods and Cast Studies* (Bolstad *et al.*, 2011) describes a notional process for conducting a situational awareness requirements analyses. The process uses goal-directed task analysis to identify a system's major goals and then to delineate the dynamic information requirements to support each of the goals.

  Bolstad *et al.* (2011) also summarize a series of situational awareness-oriented design principles that should be applied to the design of biosurveillance systems. See also *Designing for Situation Awareness: An Approach for Human-centered Design* (Endsley *et al.*, 2003) and *Designing for Situation Awareness in Complex Systems* (Endsley, 2001) for more detail.