# Degrees of Shared Awareness

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**Abstract**

Shared awareness is not a simple construct; different levels of shared awareness arise when participants have access to information that is identical (common), consistent, conflicting or some combination of these. This paper discusses how individuals achieve awareness from information, and the impact for shared awareness. It identifies six levels of "shared" awareness that may exist between two individuals, which have distinct properties. The differences between three of these: *Common Awareness*, *Potentially Shared Awareness* and *Fully Shared Awareness* are discussed in the context of an Air-to-Air scenario where one set of planes is equipped with Link-16 and the other only has access to voice communications.

## 1. Introduction

This document looks at the costs and benefits of achieving different degrees of Shared Awareness. We build on the work by Alberts et al [2001], who define Shared Awareness as a cognitive capability that builds on Shared Information. Alberts et al identify four mechanisms for developing Shared Awareness: independent observation of a common event either 1) directly or 2) though independent sensors, 3) information that is passed from one person to another, and 4) information that is shared and the fused results presented to two (or more) people. The list is clearly not complete; numerous variations to these four combinations are possible, one person may observe an event directly whilst another observes it through a sensor, one person may have fused information and another access to un-fused information.

Of greater concern is the limited treatment of what it means for information to be shared, and more importantly for awareness to be shared. Two independent observations of an event may derive different information (and thus awareness) from the event. Consider the tale of six blind men who went to see an elephant: the one who felt the side of the elephant assumed that the elephant was like a wall, the one who felt the tusk assumed that the elephant was like a spear, the one who felt the trunk thought that the elephant was like a snake, the one who felt the ear thought that the elephant was like a fan, the one who felt the knee thought that the elephant was like a tree and the one who felt the tail assumed that the elephant was like a rope [Saxe, 1963]. While each of the facts was consistent with the truth, and they distributed the information to each other, they placed a greater value on the information they had gathered, resulting in a different understanding of the situation and an argument about who was correct.

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[1] This work was conducted whilst on attachment to the RAND Corporation.

[2] This work was conducted whilst employed by the RAND Corporation.

To many in the field of network-centric warfare, this is seen as an undesirable state-of-affairs. However, it has positive points. First, the six men exchanged information and whilst they might not have trusted it all, they have a greater collective information source than they would have had individually. Second, the context, meta-information, or the framing of information is needed to determine whether information is conflicting or not. That is, if the information in the parable is viewed as "what is an elephant like" then the information from the six blind men is incorrect and conflicting. However, if the information is recast into "what are the parts of the elephant like" then the information from the six blind men is correct, related and not conflicting. Third, the men in the parable discussed their views, so they were each aware of the others' interpretations of the elephant. Thus, they would not act upon the misconception that they all had the same understanding of what an elephant is.

Finally, let's assume that the six men were separated and had to do a coordinated task concerning the elephant and that they all had the same information. The best result would occur if they fused the information and had a more complete picture of an elephant. The worst result would occur if the men only paid attention to the information they had directly retrieved. Almost as bad would be if they decided on a single interpretation. However, coordinating with an awareness of the differences of opinion could result in a satisfactory outcome. In many instances, what is required is not common awareness but awareness that is sufficient for the parties involved to be able to understand the likely actions of each other.

With this in mind, we consider different types of "shared" information and awareness.

## 2. **Shared Information**

### 2.1 ***Nature of Information***

The nature of information is a complex phenomenon that requires some discussion before information sharing is discussed. There can be information about the physical environment, information about the information environment (including meta-information) and information about the cognitive environment. Furthermore, that information can be organized in multiple ways.

Consider the location of an airplane, and assume for the moment that somehow we know that the information is about a single plane. That information can be organized in a variety of ways – for example, using Cartesian co-ordinates or polar co-ordinates, and the information can be organized over time, with historical information and future projections. When all of the information is known, it is possible to convert between different coordinate systems. However, often the information has value even when only part of the location is known (eg height, or distance from a known object) and in these cases conversion between coordinate systems may not be possible. Location itself may be part of one or more broader information elements, such as the distribution of aircraft, blue force locations, combat locations, etc.

An individual may have multiple values for the location of the same aircraft, because they were taken by different sensors, because the values were taken at different times, or because of transcription or translation errors or because of a variety of other possible causes. Thus, the information held by an individual may itself be unique, consistent (as when the location

information available is 10m +/- 2m and 9m +/- 2m East of the current location and at 10m altitude), or conflicting (as when the location is 10m +/- 1 m or 8m +/- 1m East of the current location). [3] In fact, determining consistency is not that easy. A piece of information must be consistent not only within the (possibly multiple) values available for a single piece of information, but with related information. For example, the speed, location and type of a vehicle should all be consistent. As an extreme example, consider a vehicle of type "aircraft" and altitude "-10,000m". The information is, I hope, clearly inconsistent.

Further complicating the matter is the difficulty in determining that we are talking about the same thing. In the physical domain, it may be possible to map the information about an aircraft to a real aircraft and use this meta-information to determine if the information refers to the same thing. However, even this is problematic. For example, if there are two entities close together it may be difficult to know if each set of information refers to the same or to different aircraft. In the cognitive domain where there is no aircraft to point to, this is even more difficult.

Thus, it is not a simple matter to simply line up the information held by two force entities (or even an individual) and to say what is common and what is different and how it is different without some context. Considerable effort has gone into determining information hierarchies and ontologies, but these have rarely taken off. One of the reasons may be the difficulty in framing information as discussed in the introduction. For the purposes of this paper, we therefore restrict our attention to information in the form that it is stored (or presented). Going back to the parable at the beginning, if views of each of the blind men were captured as the "elephant is like a…." then the information would be viewed as conflicting. If the blind men then determined that they were viewing different parts of the elephant and recast the data, then the new information "the parts of an elephant are like…" would not be conflicting, but would be consistent.

### 2.2 *Degrees of Information Sharing*

As previously discussed, an individual can hold information with unique values, consistent values or conflicting values. This leads to several possibilities when we compare the information held by two force elements A and B. For each information element held by A there are four broad possibilities: B does not hold the information, the information is identical to that held by B, the information is consistent with that held by B and the information conflicts with that held by B. However, in the case were A or B holds multiple values for a piece of information, the situation is more complex – there may be commonality, consistency or conflict in the sets of values held by A and B. We summarize the possibilities in the table in Figure 1.

There are three basic classes of information sharing: Common Shared Information, Consistent Shared Information and Conflicting Shared Information. Common Shared Information has the most in common – all information values are held by all participants. Consistent Information is still a very powerful level of shared information – all participants have information which is

[3] The example shows the interplay between precision and accuracy for assessing the consistency for interval measures; other techniques must be used for assessing the consistency of nominal and ordinal measures. Furthermore, in some cases it will not be sufficient to match the values of information to determine consistency in some applications. Additional information – such as any tagged meta-information or information transmitted during the same time may be required.

consistent with that held by other participants (although that information may itself be conflicting). Participants with consistent information have the potential to develop coordinated actions, with or without additional collaboration. We identify special cases of Common and Consistent Shared Information that indicate the nature of the information which is shared: that is, whether it is unique or consistent (for Common Shared Information) and whether or not the shared information is conflicting in all cases. There is a difference between Conflicting Shared Information and Shared Conflicting Information. In the latter case, both parties have all values of the information, whilst in the former each party has access to different sets of values.

We also identify the special case of Ambiguous Information, where some values are common or consistent with those held by another participant, but where there are additional conflicting values. In this case, information may conflict with information held by another participant, or with additional information held internally.

<table>
<tr><th rowspan="2">Information Held by B</th><th colspan="3">Information Held by A</th></tr>
<tr><th>Unique Information</th><th>Consistent Information</th><th>Conflicting Information</th></tr>
<tr><td>Information not held</td><td colspan="3">Original Information</td></tr>
<tr><td>All information common to that held by A</td><td>Common Shared Unique Information</td><td>Common Shared Consistent Information</td><td>Shared Conflicting Information</td></tr>
<tr><td>All information consistent or common with that held by A</td><td colspan="2">Consistent Shared Information</td><td>Consistent Shared Conflicting Information (all values held by A and B can be matched)</td></tr>
<tr><td>All information conflicts with that held by A</td><td colspan="3">Conflicting Shared Information</td></tr>
<tr><td>Some information is consistent or common and some conflicts with that held by A</td><td colspan="3">Ambiguous Shared Information</td></tr>
</table>

Figure 1: Categories of Shared Information

Finally, we identify the case were the information is not shared at all (that is one party does not hold a value for the information). We call this *Original Information*[4].

## 2.3 *Impact of Shared Information*

Shared Information between force elements is only beneficial insofar as it supports the development of Shared Awareness. To simplify the discussion we focus on only four types of Information: Original Information, Conflicting Shared Information, Consistent Shared Information and Fully Shared Information. We do not consider the special case of Collaboratively Generated Information, because while the process may result in new or different information, it has no distinct characteristics in terms of the degree of information sharing.

[4] Note that original information is that sub-set of organic information that is not held by another entity.

## 3. **Shared Awareness**

The ideal of Shared Awareness is when entities have Shared Information and are able to act on it. This means that they have internalized (a cognitive function) the information and are *aware* not only of the information held by the participants, but have some idea of how they will act on it. We call this *Comprehensive Shared Awareness*[5]. Comprehensive Shared Awareness requires more that just Shared Information; it requires compatible pre-existing mental models and an understanding of the other party's awareness, which will be influenced by a variety of factors including their emotions, physiology, beliefs and perceptions (Leedom, 2001) and their ability to access the information, and not just the information held. However, for the purposes of this paper, we are interested in the levels of Shared Awareness that result from Shared Information and meta-information about the information that has been shared.

Shared Awareness will be reduced when either the Shared Information is not available, or when the force elements are not confident of the degree of sharing. This could be because they have no knowledge of the shared information, or because they believe the information is shared, but cannot or have not confirmed that the information is available and has been correctly internalized.

Common or Consistent Shared Information is a requirement for Comprehensive Shared Awareness. However, Full Shared Information can occur without Comprehensive Shared Awareness. For example, if two force elements have the same location for a building, or the same location for an airplane at a particular point in time, then they have Full Shared Information, even if their information was obtained independently. Figure 2 shows the primary sources of information: organic information and non-organic information and how it may be shared. Organic Information is any information generated by a force element or a sensor or other information source that "reports" directly to the force element[6]. Non-organic information can come from two sources: it can be gathered (or retrieved) from the network, or it can be actively shared. Further, a force element may choose to post their organic information[7], or to actively share that information. A special type of information is collaboratively generated information, which for the purposes of this paper is considered organic to all of the sites collaborating, and actively shared. In the example above, the two force elements could have Other Organic Information that has not actively been shared and information that has not been placed on the network, but is still held in common. In these cases, we will not have Comprehensive Shared Awareness. However, even if the information has not been explicitly shared, there is still a degree of Shared Awareness. That is, the force elements may still be able to act on the

[5] Note that Full Shared Information and Full Shared Awareness as defined here apply to individual pieces of information. They are not intended to imply that all of the information is shared. If this were the case, we would have Complete Full Shared Information and Complete Full Shared Awareness.

[6] This may not be the best definition for Organic Information, but it is sufficient for the purposes of this document.

[7] In the instance of a sensor that directly transmits information to the network, we create a nominal force element that resides at the sensor, as in [Perry et al, 2003].

assumption that information has been shared[8]. Even when acting independently, those actions may be (more) synchronous because of the shared information.

*Actively Shared Information* arises when one force element deliberately passes a piece of information to another (one or more) force element(s), and the receipt of the information is acknowledged. In this case, the two (or more) force elements have the same type of information, about the same entity, with the same value. We call this *Full Shared Information.*

*Collaboratively Generated Information* is a special form of Actively Shared Information, where the value of the information is determine by the group sharing the information. For example, the group may actively fuse separate pieces of information to generate new information or to obtain an agreed value for existing information. For example, determining intent from other pieces of information.

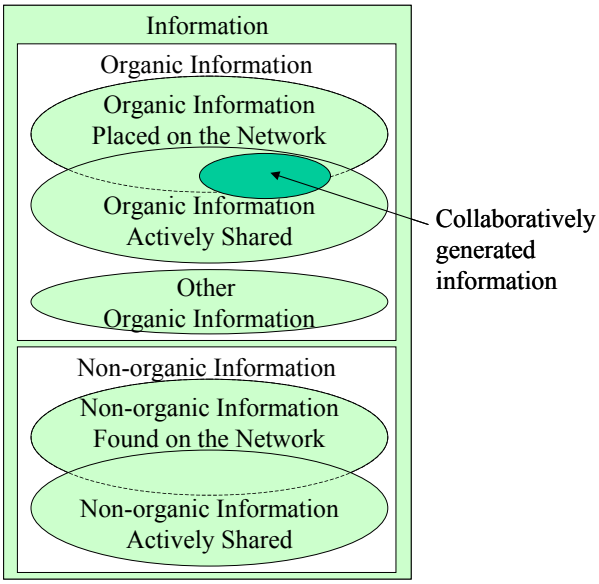


Figure 2: Information Held by A Force Element

There are numerous possible levels of awareness of sharing. For simplicity we consider only three: no awareness, awareness that other force elements may share information, and awareness that other force elements do share information (as would result from active sharing or collaboration). Of these, the middle option offers the most possible variations, force elements may know that other force elements are in an area and should also have observed an event, they may have posted information to a network with no real knowledge of whether or not that information has been used, they may have obtained information from a network without knowledge of who else has access to the information, or they may be accessing the information via a display which they know is commonly available, such as a Common Operating Picture or a Link-16 display in an F/A18. However, in terms of the impact of shared awareness, in all these

[8] We include in this category, the case where one force element has internalized a report from another force element (and thus is aware of the sharing) without informing the original participant.

cases any coordinated actions must be, to a greater or lesser degree, predicated on the assumption rather than the assurance that others are aware of the relevant information.

Figure 3 lists a range of possibilities for shared awareness for the three levels of awareness of shared information. Note that the highest level of Shared Awareness in the table is Full Shared Awareness. Together with consistent mental models, Full Shared Awareness would result in Comprehensive Shared Awareness. Note that we have grouped cells with similar properties together to simplify the following discussions.

<table>
<tr><th></th><th>Aware of Sharing</th><th>Aware of Potential Sharing</th><th>Not aware of Sharing</th></tr>
<tr><td>Common Shared Information</td><td rowspan="2">Full Shared Awareness</td><td rowspan="2">Potential Shared Awareness</td><td rowspan="2">Common Awareness</td></tr>
<tr><td>Consistent Shared Information</td></tr>
<tr><td>Conflicting Shared Information</td><td rowspan="3">N/A</td><td rowspan="2">Conflicting Shared Awareness</td><td rowspan="2">Conflicting Awareness</td></tr>
<tr><td>Ambiguous Information</td></tr>
<tr><td>Original Information</td><td colspan="2">Original Awareness</td></tr>
</table>

Figure 3: Awareness and Understanding

Full Shared Awareness is the highest level of shared awareness. The participants are aware that they share information to a required level of consistency. Shared awareness may not be sufficient to lead to synchronized plans. For example, if some of the shared information is itself conflicting, then agreement on how to treat the conflict (either through mental models or otherwise) is also required[9]. Also, note that it is not necessary for the information to be the same. For example, if a location is available to a high level of accuracy, but only a low level of accuracy is required, then it is sufficient for the information to be shared at the lower level.[10]

Potential Shared Awareness will arise in many more circumstances, both through deliberate planning and circumstance. The disadvantage of potential shared awareness is that the shared awareness cannot be relied upon and in many cases there is no way to distinguish it from Conflicting Shared Awareness.

Common Awareness will also arise in many circumstances. In this case the participants have common information, but are not aware of it. Thus, they cannot plan based on potentially shared information, but the existence of shared awareness may lead to additional unplanned synergies in activities.

In Conflicting Shared Awareness, the participants have different (and conflicting) values for the same information, and any action that relies upon the belief that the information is shared is likely to be counter-productive – even more so than when the potential for shared awareness is not known.

[9] This could be modeled as a piece of meta-information.

[10] In practice, this would require knowledge of the required level of accuracy, but provided people are aware of the differences, or use the lower level for co-dependent activities, this is sufficient for shared awareness.

Conflicting Awareness arises when the participants have different (and conflicting) values for the same information. This can lead to uncoordinated actions, but it is probably better than Conflicting Shared Awareness where force elements may rely on support that is using conflicting information.

Unique Awareness arises when information is not shared. It is likely that some unique awareness will always exist, either due to direct observations, security concerns, or limitations in our networks. There are two cases worth considering within the Unique Awareness. The first is when the uniqueness is accidental. The second case, when the awareness is deliberately unique, is much more interesting. For example, this may be the case for forces involved in covert ops. In this case, the force element can factor the uniqueness of their awareness into their plans (for example, how is X likely to act if they don't know where I am).

## 4. Obtaining Shared Awareness

Another approach to assessing Shared Awareness is to consider the perspective of individual force elements, such as pilots, and to consider their awareness or perceptions of other force elements' information. For simplicity, we consider the case where there are two force elements of interest. Using the categories of information introduced in Figure 2, we can identify four broad categories of information exchange that lead to the development of awareness of another's information, as shown in Figure 4.

When the entities actively exchange information, they exchange both organic (1) and non-organic (3) information. As a result of the active sharing, both parties are aware that the other has received the information, resulting in Fully Shared Awareness for those information elements (shown in dark yellow in Figure 4).

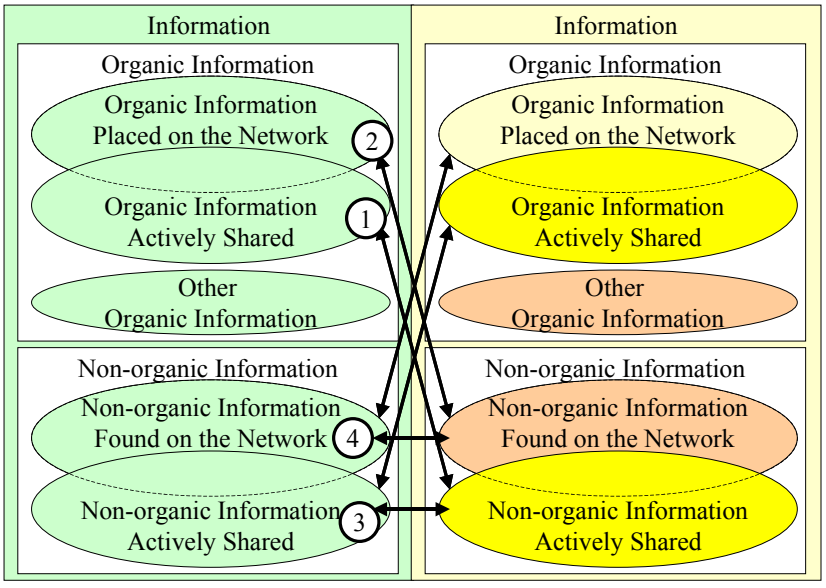


Figure 4:An Individual's Information (Left) and Their Awareness of Another's Information (Right)

The entities also explicitly (eg voice communications) and implicitly (eg much of link 16 communications) place information on the network. When this information comes directly from

the second entity's organic sensors (2), the first entity knows that the information is available to the second. Furthermore, as well as having identical information, it is likely that the second entity is aware of the information since it comes from their organic sensors. Thus, the two entities have Potential Shared Awareness[11].

When the information on the network comes from other sources (4), it is much more difficult to determine whether or not the other force entity is likely to have retrieved the information from the network. Where the network explicitly broadcasts information to all participants (eg most information on Link-16 or on a voice network) then it is reasonable to assume that they have the information, and if the information is made available – via voice or situation displays then we again have Potential Shared Awareness. (We note that the longer the information is available, the more likely is Shared Awareness). We note that there is also the potential for individuals' organic information that has not been shared to be similar. For example, two pilots in nearby planes will probably assume that they are tracking the same planes, although they may not actively share changes in status or new detections. Again, we may have Potential Shared Awareness.

In these latter two cases (Organic, Unshared Information, and General Information from the Network), Potential Shared Awareness may not always arise. Sometimes, the information available to the two participants will be conflicting rather than shared (for example, where there are multiple sources of information on the network, or where one entity's sensors are misaligned), or one of the entities may not have obtained the information, due to sensor or network problems, or other cognitive demands. Thus, we may also have Conflicting Shared Awareness, Conflicting Awareness or Original Awareness.

### 4.1 *Costs of Obtaining Shared Awareness*

Figure 5 shows a simple representation of the process of sharing information and developing shared awareness. To begin with, we ignore the dashed line and consider the deliberate sharing of information between two force elements, **A** and **B**. Before sharing the information, **A** must be aware of it (1)[12]. In general, that means the need to *retrieve* the information and cognitively interpret it or *integrate it* with existing information and determine whether or not to make the information more widely available. To make the information more widely available they either need to *post* the information (2) and transmit it (3), or they may be able to simply *transmit* the original information (dashed line). Here, posting means to convert the information into a suitable form for transmitting. Posting may convert all of the original information, or only important elements. (Note that while the steps are shown as sequential, for a single piece of information, posting and transmitting information may be tightly coupled.) Force element **B** must know that the information exists, and retrieve and integrate it for Shared Awareness (4).[13]

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[11] Note that we have not required the first entity to be aware (or potential aware) that the second entity has the information, and note that a bi-directional link would be approaching Active Sharing, and thus, Fully Shared Awareness.

[12] We note that if node **A** were only a relay point, then integration would not be required. However, we ignore this situation since we are ultimately interested in the development of Shared Awareness.

[13] Note that if step 3 and either step 1 or 4 occur then we may have *Potential Shared Awareness*. This is independent of whether the information is placed on the network or transmitted to a single recipient, and depends primarily on whether or not the

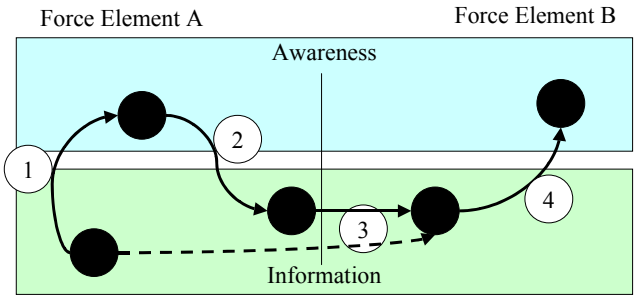


Figure 5: Process of Sharing Information

## 5. An Example

We consider an analysis of Voice versus Link-16 and Voice to illustrate these concepts[14]. In particular, we focus on the development of Shared Awareness at a single point in time in a simple Air-to-Air scenario as shown in Figure 6. There are four red and four blue fighters operating in pairs, with an AWACS supporting the four blue fighters. The AWACS radar covers a much broader area, but provides less accurate and frequent updates for the position and speed than are available from the fighter aircrafts' systems. For simplicity, we ignore the possibility of sensor or human error and assume that all of the aircraft are able to detect and identify all aircraft within their respective radar's coverage[15].

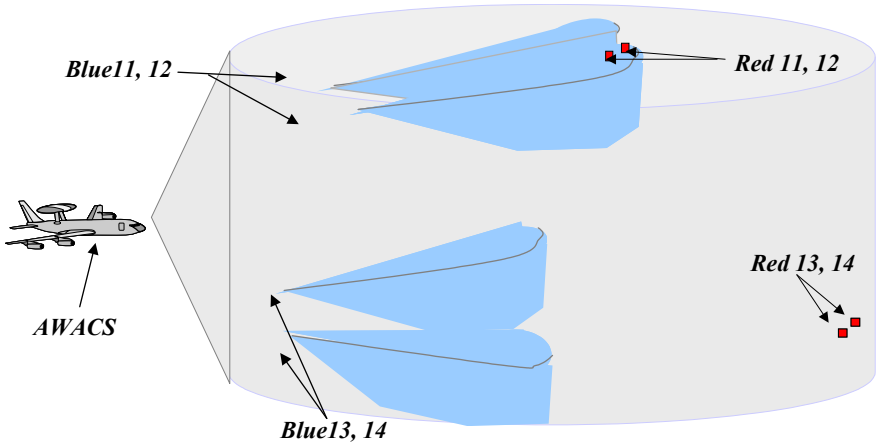


Figure 6: A single Air-to-Air Scenario

In accordance with Figure 6, we assume organic information availability as shown in Figure 7. Remembering that the AWACS information is not as reliable as the information from the fighter aircraft, we have shown the best sources of information in italics in Figure 7. (We assume that

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recipient wants the information and knows where to find the information. For *Full Shared Awareness* we also require acknowledgement that the information was correctly received. If information is misinterpreted, then we may also have *Conflicting Shared Awareness.*

[14] This example is taken from [Gonzales et al, 2003].

[15] This approach is consistent with previous unpublished analyses by RAND and we also use this approach in order to avoid having to discuss conflict resolution strategies.

the best sources are the force assets themselves, then the blue fighters, then the AWACS. In the event that two entities have the same quality information, we indicate both in italics.)

| **Blue Asset** | **Organic Information** | |
|---|---|---|
| | **Blue** | **Red** |
| **AWACS** | AWACS<br>Blue 11, 12, 13, 14 | Red 11, 12, *13, 14* |
| **Blue 11** | *Blue 11* | *Red 11, 12* |
| **Blue 12** | Blue 11, *12* | *Red 11* |
| **Blue 13** | *Blue 13* | |
| **Blue 14** | Blue 13, *14* | |

Figure 7: Blue Organic Information

Using the elements of information sharing – integrate, post and transmit and receive – discussed in Figure 5, we identify the elements given in Figure 8 as those associated with sharing information with both voice and Link-16. We assume that the time required to retrieving and integrating a track from a radar display is the same as the time required of retrieving and integration a visual from a Link-16 display and call this visual retrieval and integration time *t.* We note that voice retrieval must occur at the same time as voice transmission, *v*, so that *v* is less than voice retrieval and integration time (*r*). In general, we also assume that the link transmission time *l* is significantly less that *v* and that $t < r$ since the visual representation means that transformation of the frame of reference is not required.

| | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| **Voice Only** | Visual Retrieval and Integration, *t* | Voice Post, *p* | Voice Transmission, *v* | Voice Retrieval and Integration, *r* |
| **Link 16** | Visual Retrieval and Integration, *t* | N/A | Link Transmission, *l* | Visual Retrieval and Integration, *t* |

Figure 8: Time Elements to Share Information for Link-16 and Voice

In addition to the raw information and the time elements of sharing, we need to make some assumptions about the communications and information exchange protocols being used. We assume that communications are limited to those needed to maintain the *potential* of shared awareness between all five blue assets. Thus, we are able to restrict our analysis of Link-16 and Voice to consideration of the Link-16 component for this example. If acknowledgements or the generation of Full Shared Awareness were required then both the Link-16 and Voice and the Voice-Only systems would have additional voice communications requirements.

We also assume that if information is made available, then others will successfully integrate it cognitively. That is, there are no cognition errors. Whilst this is not realistic, the time required for the posting, transmitting and integrating information can be modified to reflect the time required to repeat information that is not understood. This, together with the assumptions of similar radar capabilities and a loss-less network means that there is no Conflicting Shared Awareness or Conflicting Awareness. All awareness is Potential Shared Awareness, Common Awareness or Original Awareness. Original Awareness occurs when only one force element is aware of a piece of information. Common Awareness occurs when multiple force elements hold the piece of information, but are not aware that others may share it.

In order to compare the levels of the three forms of awareness, we examine the information held by each pair of aircraft. There are 5 * 4 possible ordered pairs of aircraft and 9 entities to be tracked for a total of 180 possible instances of Common or Potential Shared Awareness[16].

As given in Figure 7, there are 3 entities (AWACS, Red 13, Red 14) for which only one track is held (0 pairs), 3 entities (Blue 12, Blue 14, Red 12) for which tracks are held by two entities (two ordered pairs) and three entities for which tracks (Blue 11, Blue 13, Red 11) are held by three entities (six ordered pairs). Thus there are 3*0 + 3*2 + 3*6 = 24 pairs of common information. The level of Common Awareness is therefore 24/180 = 0.13.

Depending on the pilots' knowledge of each others' training, location and equipment, we can assume a degree of Potential Shared Awareness prior to any information sharing. For this analysis we make the following assumptions: 1) all pilots believe that AWACS has a level of awareness of the entire battlespace and 2) if a pilot's location is known, it is assumed that they are aware of the information which a fully-functioning radar should produce. Using these assumptions, we see that Potential Shared Awareness is not a symmetric function. That is, the wingmen know the location of their leads and can assume sharing, whilst the converse is not true. For example, Blue 11 is not aware that Blue 12 also holds its location and that of Red 11. Similarly, Blue 13 is not aware that Blue 14 holds its location. All other relationships in Figure 7 are known. Thus there are three fewer tracks for which Potential Shared Awareness exists than for Common Awareness[17]. Thus, Potential Shared Awareness = 21/180 = 0.11. If the leads assume that their wingmen are near, the level rises to that previously given for Common Awareness of 0.13.

In considering the implications of networking the force on Potential Shared Awareness, the order in which the nodes transmit information affects the time and cognitive load required to achieve Potential Shared Awareness of all information elements. Since the communications protocols are relatively straightforward for Link-16, we consider this case first.

### 5.1 *Link-16*

In the case of Link-16 we assume that all tracks are transmitted to all of the assets, and that they are automatically fused so that the displays will only show one track for each entity. Since all of the entities are tracked by at least one source, this results in the maximal level of Potential Shared Awareness, that is 1. From Figure 7 we have that there are 18 tracks held by the five blue assets, the time required to transmit each one is $l$ so the total time to transmit the tracks is 18$l$.

To obtain the most up-to-date information (and develop shared awareness) all of the assets need simply to retrieve and integrate the information (after all of the tracks have been received). Since the visual representation is easy to transform there is little or no benefit to be gained from previous situation awareness so we have that the 5 blue assets each retrieve and integrate tracks from the 9 force entities in the battlespace at a time of $t$ each and a total time of 45$t$.

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[16] Note that there are other ways of assessing common awareness, but as used in this document, potential awareness is an asymmetric relationship between pairs of entities, and this allows for a common method of normalization.

[17] Note that it is possible to identify further levels of shared awareness that are symmetrical, that take into account that the wingmen will be aware that the leads don't share the information.

The total time required to achieve maximal Potential Shared Awareness across all information elements for Link-16 is $18l + 45t$.

### 5.2 *Voice*

Using a similar philosophy with only voice is very expensive. The time required for each asset to transmit their tracks is 18 times the combined time to retrieve the track, post the track, and transmit the track or $18(t+p+v)$. Each of these 18 tracks can be retrieved and integrated by the 4 force elements not transmitting the tracks for a time of $72r$. The total time required to retrieve the tracks via voice in this manner is $18(t+p+v) + 72r$.

#### 5.2.1 *A Simple Communications Procedure*

Fortunately, even with only voice we can do much better by using some simple communications protocols. First, we can limit the number of times which information is transmitted, so that each piece of information is transmitted only once, unless an asset has more accurate information than that previously reported. (For the purposes of this procedure, we ignore differences due to the movement of the aircraft). What we want ideally is for only those assets with the best track information to transmit. If the aircraft are operating together and have some knowledge of the capabilities of the other blue aircraft, this is simple to achieve. We simply get each of the fighters to report their own details and those of any unreported red entities before the AWACS reports.

Since each entity in the battlespace will be reported exactly once using this procedure, we have 9 transmissions required a time of $9(t+p+v)$ and 4 times 9 or 36 information retrievals and integrations for a total time of $9(t+p+v) + 36r$, or exactly half the previous time to achieve Potential Shared Awareness for all information elements. We note that the time savings will increase with the number of entities in the battlespace.

We note that using this approach, there are three times at which redundant information is received and integrated: Blue 11's information is transmitted to Blue 12, and similarly for Blue 13 and Blue 14, and Red 11's information is exchanged between Blue 11 and Blue 12. While it might appear that additional savings could be made by more finely tuned procedures, such as using the wingmen to exchange information, this would have a limited impact on the total time required, because it would incur additional time penalties to post the information. Furthermore, this model is more robust to variations in the assumptions. For example, if two aircraft held different locations for the same entity, this could be detected by this approach.

## 6. **Conclusions**

This document has discussed the creation of various levels of Shared Awareness as derived from Shared Information. The model is more detailed than previous models, but still has limitations that need to be addressed in future research including the explicit consideration of prior knowledge, mental-models, decision support models and tools and the impact of emotions, physiology, beliefs and perceptions and [Leedom, 2001]. In its current form the model allows an understanding of the level of Shared Awareness that is desired and achieved, as illustrated in the analysis of the transmission times associated with a simple Air-to-Air scenario where we have assumed "perfect" information sources and loss-less information distribution.

The following analysis shows that less time is required to transmit the information using Link-16 than via Voice in this example:

$$\begin{aligned} Voice - Link16 &= \left(9(t+p+v)+36r\right)-\left(18l+45t\right) \\ &= 9p+9v+36r-18l-36t \\ &> 9p+9v-18l \qquad \text{assuming } r > t \\ &> 0 \qquad \text{assuming } p \text{ and } v > l \end{aligned}$$

Furthermore, the times associated with Link-16 are more robust to assumptions of perfect information sources and distribution and there is no requirement for coordination. That is, people can update their Awareness at the time that is most beneficial to them.

Future analysis could consider other benefits of Link-16 and the time required to generate Shared Awareness where information sources are inaccurate or where information is lost during transmission, or investigate the costs associated with posting, transmitting and retrieving information via voice and visual means, and the effects of information aging in both environments.

## 7. **References**


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