2006 CCRTS
The State of the Art and the State of the Practice

"*A Revised Calculation on the Value of Networking as Applied to Airborne Platforms*"

TOPICS:
Social Domain Issues
Network-Centric Metrics
C2 Concepts and Organization

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Abstract

Over the last 10-15 years, much of society has taken for granted the value of having networked capabilities. Society has enjoyed the benefits of networking without considering a return on investment, or if a bigger network is always better. Over the years, various laws have been proposed to approximate the value of a network. These have ranged from Sarnoff's Law for an asymmetrical network, to Metcalfe's Law for one-to-one contacts, to Reed's Law for Group Forming Networks such as Internet Protocol (IP) networks. In reality there are many types of networks – phone, fax, radio, television, IP, satellite, line of sight radio system, etc. – and the current laws for approximating the value of a network fail to take into account key items such as that more connections may not always be better, the cost to join a network, the time to join a network, and negative costs of some connections. The authors will propose that just as trees don't grow to the sky, neither does the value of any network. This paper will present a relationship between the value of a network and the Air Force's current challenge with developing and justifying the cost of an Airborne Network.

Introduction

The Air Force (AF) is in the early stages of designing and implementing an Airborne Network (AN). This paper presents a methodology to place a value on networks used for military purposes. The hope is that this network value can be used to assist in building a strategy to design and implement the AN.

The AF currently uses many networks. These networks were designed for specific purposes to meet particular mission needs. Examples of networks that the AF employs include:

1. Point-to-point serial connections to pass large imagery files
2. Link 16 network to exchange mission information between airborne and ground nodes
3. Situational Awareness Data Link (SADL) to provide the locations of ground assets to Close Air Support (CAS) aircraft
4. SIPRNET, an IP-based network, to pass classified information
5. NIPRNET, the military version of the World Wide Web for unclassified information

The above list is a representative sample but not complete. Each network may contain information that is unique and not available on the other networks. Very few nodes have access to all of the networks. Due to different protocols or classifications, nodes that do have access to multiple networks must maintain distinct and separate equipment. The classification issue is not addressed in this paper.

The ultimate goal is to converge upon a common protocol, possibly IP. IP is mentioned mainly because of its ubiquitous nature in networking environments today. IP may not be the best protocol for all situations but it provides a common standard to allow the sharing of information.

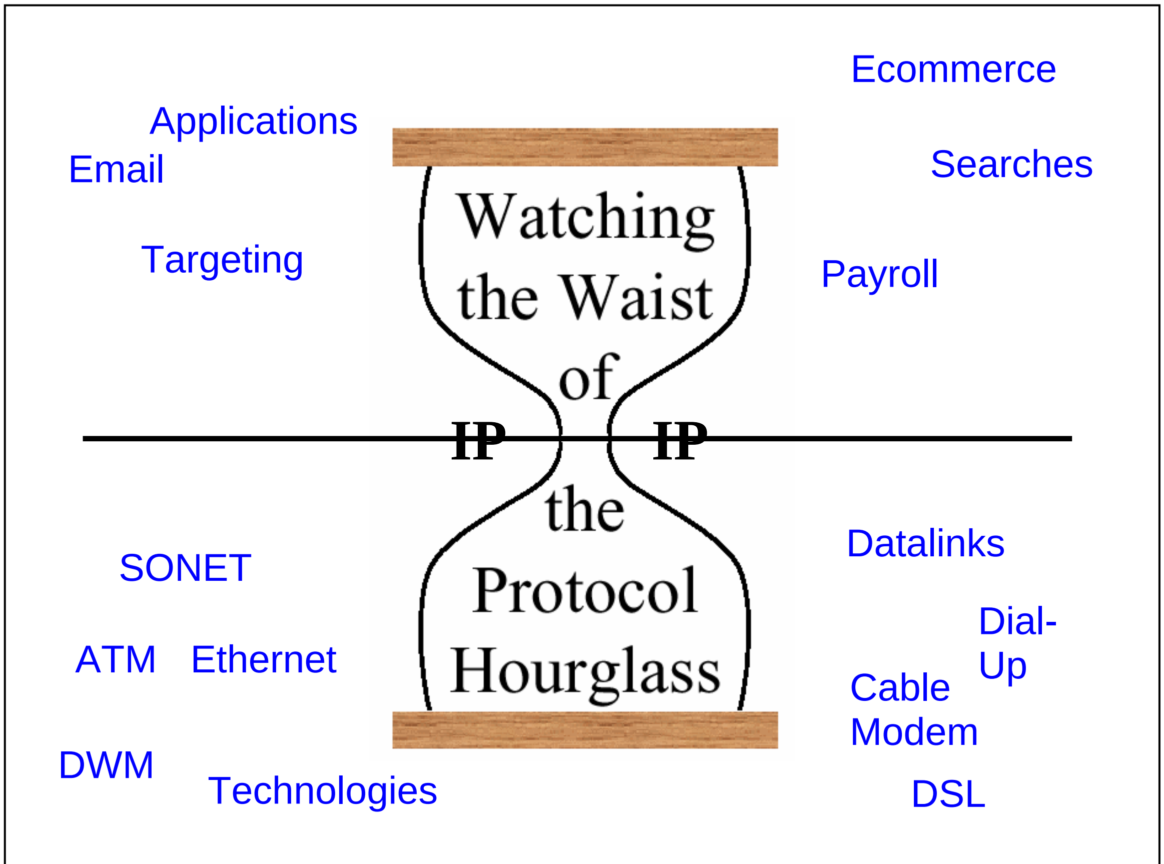

Figure 1. What protocol to converge on?[1]

Several questions must be answered in designing the AN. Below are a few example questions, given to stimulate thought as we work through the issues.

- What is the prioritization of networks and information?
- Is the IP protocol the optimal solution, and if not, what other protocols need to be developed to meet the demanding requirements of an AN?
- Can the non-IP networks currently in use be successfully converted to the necessary protocol to accomplish the mission? Should gateways be developed? Should all of the information from a non-IP network be passed through the gateway or only a critical subset?

This paper proposes a way to value military networks in order to assist in the design and implementation of the AN. The paper begins by looking at networks as

[1] "Loose Couplers: An Enterprise Data Strategy," by Rich Byrne, July 7, 2005

critical infrastructure. We discuss networks from a private sector viewpoint and then examine various methods used to value the network. The paper then looks at the network from the military perspective and discusses other laws that impact a network's value such as the Power Law, Zipf's Law and complexity. The paper concludes with a methodology for determining the value of a network from the military perspective.

Networks Are Infrastructure

In their truest essence, networks allow people or computers to share information. Networks have become an integral part of our lives. We use them to communicate, work, play, shop, invest, learn, manage our time, and stay abreast of current events. Yet, much like electricity or highways, we take information networks for granted. We plan our efforts assuming that the information will be accessible via the network and only when the network is not available do we really take note of its value.

Networks such as the telephone system, broadcast television or the internet have become infrastructure. Just as the interstate highways support our national transportation system, information networks have become essential components to our economy and quality of life.

Information networks certainly have value but what price to you put on it? How do you make investment decisions on capabilities that are so intertwined with our daily lives? Capabilities that are like infrastructure – expensive to implement at first but once put in place, become normal, expected and even essential components of our lives.

The Definition of Value

Just as "Beauty is in the eye of the beholder", the definition of *value* is subject to one's perspective. In this paper, the characterization of network value will be done from two situational perspectives: the private sector and the military community (more specifically, the AN). In addition, there is a temporal aspect to perspective and both of these situational views will be examined from the timeframes of (1) network establishment and (2) network use. For the purposes of this paper, the phrase "network establishment" refers to the creation (design, development, and building) of a particular network. The timeframe referred to as "network use" is defined as the period after the network is in place and being used.

All of the network value definitions developed for the private sector assumes that the network has been established. Figure 1 and the following paragraphs provide the definitions to be examined and discuss the situational and temporal perspectives from which they were derived. Please note that the authors were not able to find any particular law or equation for establishing a network in the private sector. This area is purely a business decision based on that particular organization's needs.

	Private Sector	Military
Network Establishment		Dahlgren & Evans
Network Use	Sarnoff's Law Metcalfe's Law Reed's Law Oldslyko & Tilley	Dahlgren & Evans

Figure 2. Value Definition Perspectives

Value of the Network from a Private Sector Perspective

The private sector calculates business ventures with an expectation of some Return on Investment (ROI). Networks are no exception. Several "Laws" have been proposed to quantify value of the network: Sarnoff, Metcalfe, Reed, and Oldzlyko & Tilley. Temporally, all of these laws look at value from the perspective of the "network use timeframe" not "network establishment." They assume that:

1. The network is in place and easily accessible. The physical connection to the network has been established (fiber connections to a LAN, modem to a telephone line, wireless hub, TV antenna, etc.)
2. The user pays the cost to join the network. The cost to join the network is minimal (purchase TV/cable, telephone/service, or computer/ISP services)
3. The time to join a network is minimal. If I want to use the phone, I pick it up and make the call. Or if I am new to town and just bought a home, then I purchase a phone and have the telephone company activate my service. The point is that if I want to call someone, I don't have to determine which phone network the person I'm calling is a part of, and don't need to create a gateway for my network to talk to her network. Making the phone call is easy and takes little time.

Sarnoff's Law

David Sarnoff placed a value on the broadcast network. He stated that the value of a broadcast to advertisers was proportional to the number of people reached; V=N. Essentially, this law says that advertisers should pay more money per 30 second commercial for a top rated show than for a show that fails to draw a large audience. The extreme example of this law is the cost per 30 second commercial each year during the Super Bowl.

Over the years, Sarnoff's Law has been somewhat revised to take into account the demographics of the viewers for each show. Current applications of this law now focus on the number of viewers within various demographic groups. For instance, many shows draw the 16-34 year old crowd that tends to have more disposable money.

Makers of products that are generally used by senior citizens probably won't advertise on a teenage oriented show. The evolution of Sarnoff's law appears to follow:

Vnetwork = $\sum$ V(30 minute time slots in a year)
There are 17520 – 30 minute time slots in a year

Metcalfe's Law

Metcalf values a network by the number of users on the system. Essentially, Metcalf values a network by the number of one-to-one possible connections that can be made over the network. $V_N = n(n-1) = n^2 - n$
where

V_N is the value of the network
n is the number of users on the network

Unfortunately, Metcalf's Law was often used during the Internet Bubble to justify the value of .com companies. Essentially companies were valued in proportion to the number of possible customers on the network and then also by the number of pairs of eyeballs that would see an advertisement on a web page. As the size of the Internet grew, the expected values of the .com companies also grew. Unfortunately, these calculations of valuations did not take into account the percentage of viewers that were interested in the specific product. Valuing a company in this manner was akin to valuing a traditional company by the size of its advertising budget. The failure of analysts to focus on earnings led to the loss of billions of dollars invested in companies that actually lacked a customer base as opposed to a potential eyeball base on the Internet. In this way, Metcalf's Law was less exact than Sarnoff's original law and far less exact than the outgrowths to Sarnoff's Law that were based on viewer demographics.

A significant fallacy of Metcalf's Law is that all connections have an equal value. This could not be further from the truth. While the white pages of a city may have hundreds of thousands of names, each user will likely use only a very small fraction of those possible connections. Regarding the Internet and possible connections, many connections such as spam and viruses will decrease the value of a network.

Reed's Law

Reed's Law is another law that was developed in an attempt to value a network. He believed that the utility of large networks comes not only from broadcast capability as shown by Sarnoff, or the one-to-one transactions as shown by Metcalf, but also from the groups that can be formed from large networks. This leads to the value of the network scaling exponentially with the size of the networks. Reed believed that the number of possible subgroups of n people is 2^n. Reed understood that the value of each group would differ, and that the value of each group might be very small. Reed focused instead on the cumulative value of all of the possible subgroups to dominate the calculation.[2]

Reed asserted that when a network consisted of a small number of participants that the value of the network actually followed Sarnoff's law. Reed believed that as the network grew that the transactions represented by Metcalf's law would become the dominant factor in valuing the network. Reed proceeded to go further with his own addition to valuing networks by asserting that as networks become much larger, that groups form and become the dominant value provided by the network. The following equation describes Reed's complete law:

$$V_N = an + bn^2 + c2^n$$
$$a >> b >> c$$

While Reed claims that the value of each connection differs, the equation as he has stated it does not provide for a difference in the value of the connections. Additionally, Reed does not provide definitive cutoffs for when the transactional portion of the equation becomes more valuable than the broadcast portion of the equation, or when the group forming section is more valuable than the transactional portion of the equation. Reed admits that a single person cannot actively participate in connections to every network member. Reed views the value of the large number of connections coming from the option to use those connections if ever needed. In many ways, this is similar to a financial option that can be bought but does not need to be exercised unless it shows value to the user.

Odlyzko & Tilly

Odlyzko & Tilly assert that Metcalfe's Law and Reed's Law both significantly overstate the value of a communication network. In their place, they propose that the value of a network is $V = N\log(N)$. This rule captures the advantage that general connectivity networks have over broadcast networks. Odlyzko and Tilly describe that not all connections are of equal value and discuss the value of locality both geographically and from an informational perspective. Odlyzko and Tilly have gone to great lengths to ensure they don't overstate the value of the network, and their value curve actually underscores the network value when compared to Sarnoff's law until $N=10$. For $N>10$ then Odlyzko and Tilly's calculation shows a higher network value than Sarnoff, but still far less than Metcalf or Reed. Essentially Odlyzko and Tilly have discounted the value of the potential options for connectivity that Reed's formula relies upon.[3]

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[2] "That Sneaky Exponential – Beyond Metcalfe's Law to the Power of Community Building", by David P. Reed, *Context* Magazine, Spring 1999

[3] "A Refutation of Metcalfe's Law and a Better Estimate for the Value of Networks and Network Interconnections" by Andrew Odlyzko and Benjamin Tilly, March 2, 2005

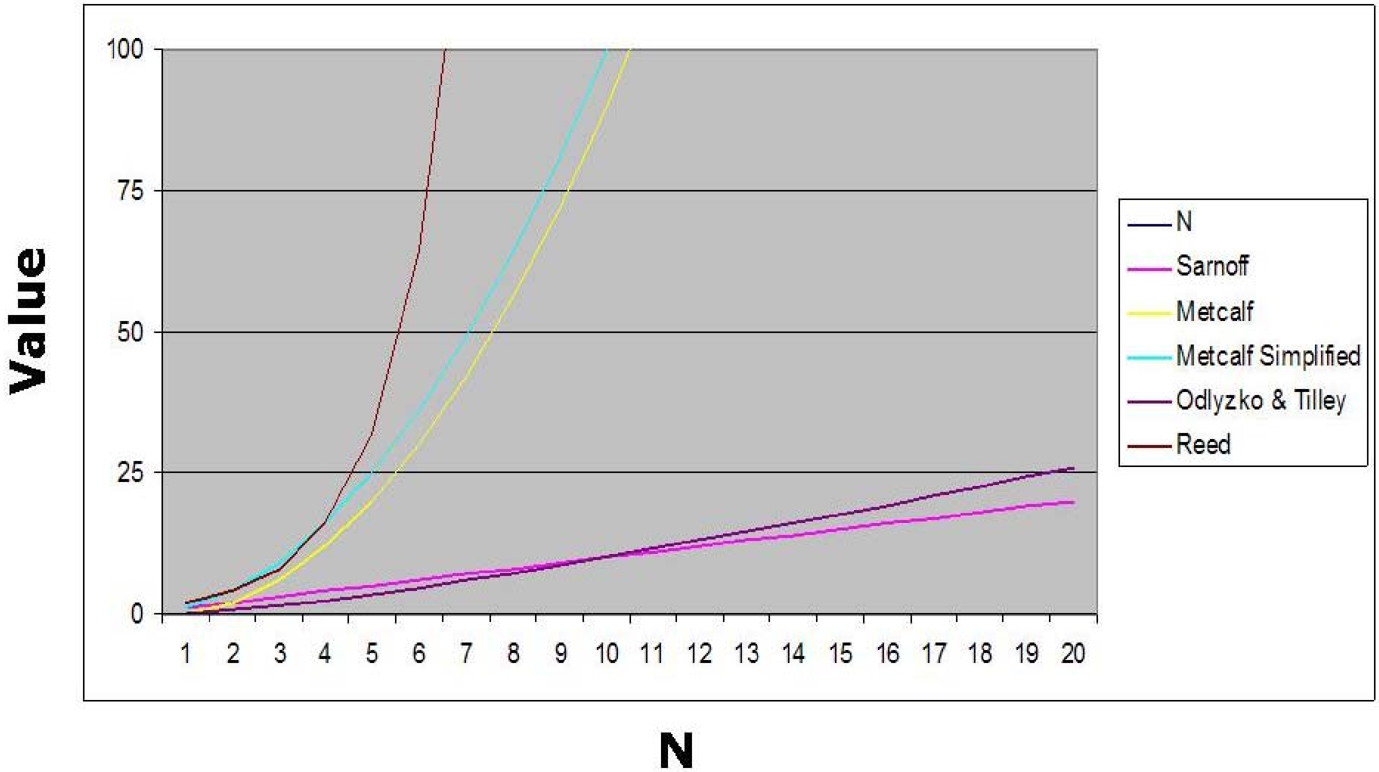

Figure 3. Private Sector Value of a Network. (Sarnoff, Metcalfe, Reed, and Odlyzko & Tilly)

Summary Private Sector Definition of Value

All of the Value Laws from the private sector can be summarized by the notion that the more people in the network, then the more valuable the network. Each law may greatly differ on the amount of value but in general, it is a positive correlation between numbers of users on the network and the value.

Network Value from a Military Perspective

Now let's change the perspective. In the military culture, the ultimate goal is not profit, but to accomplish the mission. So the definition of networking value is going to be different from the Wall Street point of view. Since the desired AN does not yet exist, we must consider not only the value in using the network but initially, the creation of the AN.

The use of military networks to accomplish a mission has some unique characteristics. A military mission will require less ad hoc searching than a casual user on the Internet. The military mission will necessitate specific pieces of information be obtained from pre-determined, authoritative sources. The encryption of data and the protection from intrusion is prevalent in the military environment. Some missions may require very reliable connections and may necessitate redundant links or alternate means of connecting to the same information. The value of the military network in both the establishment of the network and use of the network phases can be determined by examining some key concepts. The next few sections will describe these concepts in more detail; they include:

- Communities of Interest
- Cost and time for a COI to join the network
- Power Law
- Zipf's Law
- Complexity

Communities of Interest

The military mission is not dependent upon the quantity of individuals and the spending power they represent but from unique items of information that specific organizations work together to create. These organizations or collections of individuals who produce these specific information products can be called Communities of Interest (COIs).

In support of their operations, the military has developed a number of COIs. These COIs can be based on organization, function, or social network. Some COIs include force planning, Time Sensitive Targeting (TST) execution, friendly order of battle, specific aircraft, etc. The development of these COIs has not only aided in the actual execution of military missions, but also in the procurement of systems to enable these COIs to better perform their missions. In some cases specific networks, such as Link 16 and the Distributed Common Ground Station Wide Area Network (DCGS WAN), have been built to support these COIs. Whereas many civilians actually enjoy searching the Internet for information, the military missions have a time critical component that demands they have pre-established connectivity and that any ad hoc activities are minimized.

The value of each COI is directly correlated to the value of the military network. The amount of value that COI provides is specific to the particular mission. Some COIs provide information that is absolutely critical to the accomplishment of the mission and that information must be accessible on the network. Other COIs only develop products that peripherally assist in the accomplishment of a mission.

In establishing the network, the identification and valuing of the COIs is essential. These COI values allow the designers to prioritize the implementation.

In using the network, the value of the COIs is important because it allows the user to pre-determine the location from where information products will be obtained. The user can also look at the information products needed and determine if there are any gaps in the information.

Cost to Join the Network

Once again, perspective is important when determining value. In establishing or creating the network, the cost to join is, essentially, the amount of dollars and manpower it takes to install the necessary equipment on the aircraft to interconnect COIs so that the necessary information can be transferred. An example of this cost would be gateways to convert network information using other protocols into a common standard.

Also the reliability of the network can be a cost. If a piece of information is absolutely crucial to accomplishing the mission and the redundant connections are required to assure its delivery, then the cost goes up.

Time to Join the Network

When establishing the network, time is a critical factor. An Enterprise view must be taken to ensure that the mission can be accomplished as each COI moves toward the capability of participating in the network. The time required to install and integrate a system on the aircraft can be quite long. The network design, and the evaluation of competing designs, should be judged on the time required for an additional COI to be joined to the network. While the necessary equipment to join a network may be installable on the aircraft, the network should also be judged by the time and cost for additional COIs to be used on the network.

Impedances

Even if networks can be easily and inexpensively installed, their design should be evaluated against any design challenges that lead to impedances to effectively using the network. The following discussions on Zipf's Law and on Complexity are two key impedances in using a network.

Zipf's Law of Distance

COIs can be weaker or stronger due to a number of possible situations. Zipf's Law was developed to explain why communications is often more frequent in the local area (within the AOR) and less frequent between people separated by a large distance (out of the theater).[4] Modern telecommunications systems have reduced the impacts of geographic distances. Distances now may be more analogous to the impedance of

[4] "A Refutation of Metcalfe's Law and a Better Estimate for the Value of Networks and Network Interconnections" by Andrew Odlyzko and Benjamin Tilly, March 2, 2005

gaining access to information. This impedance can relate to the number of mouse clicks required to find the correct information.

In establishing a network, a good design will need to consider Zipf's Law in order to minimize impedance to maximize network value. Rectifying some impedances will likely include such areas as Human System Interface and common network architecture considerations. For instance, Zipf's Law is important, especially to pilots who have a great deal of tasks and cannot afford additional network distance penalties. On the other hand, a network design that facilitates the use of machine-to-machine data transfers, where possible, minimizes the distance penalty.

Complexity

In many areas of life, we approach a point where an increase in quantity no longer adds value and often diminishes overall value. While Sarnoff, Metcalf, and Reed have supported the idea that networks grow in value as they grow in size, the reality may be that the complexity experienced by dealing with too large a network may override the collaboration benefits that are experienced by adding more members. The below diagram is a representation of a situation where the complexity remains relatively constant for some time as the number of nodes increases, and then the complexity quickly rises with the addition of relatively few nodes. At some point, the complexity reaches a maximum level where the node or the network cannot handle additional nodes.

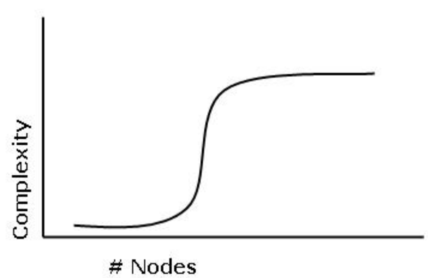

Figure 4. Complexity & # Nodes[5]

Information overload is a situation where the nodes can no longer effectively deal with increasing information or complexity. While the quantity of complexity and information experienced from interacting with each node will differ, the law of large numbers leads us to believe that a random sampling of a large quantity of nodes will lead to this situation for most nodes. Just as quantity of information disseminated by each node differs, the quantity of information each node can handle will also differ. A network design that facilitates the use of machine-to-machine data transfers, where possible, minimizes the complexity problem.

[5] "Complexity Theory and Network Centric Warfare," by James Moffat, August 2004

Power Law

Consideration of the Power Law will be essential to designing an effective network. Many students of math were taught over the years to follow the Bell Curve. Essentially the Bell Curve says that there is a distribution of items (i.e., test scores) around an average. Applying the Bell Curve to the concept of phone or Internet connections would lead people to believe that most people/companies/web pages have a normal distribution of the number of connections around a certain mean number. That would lead readers to believe that very few users would have a small number of connections (say one or two). Studies on the Internet have shown a very different distribution on the number of connections for each Internet site. The Power Law Distribution, as shown in the right hand side of figure 4, shows that most Internet nodes have a few active links. Those nodes with many links tend to be the Internet Service Providers (ISP) or the web sites for the large search engines.

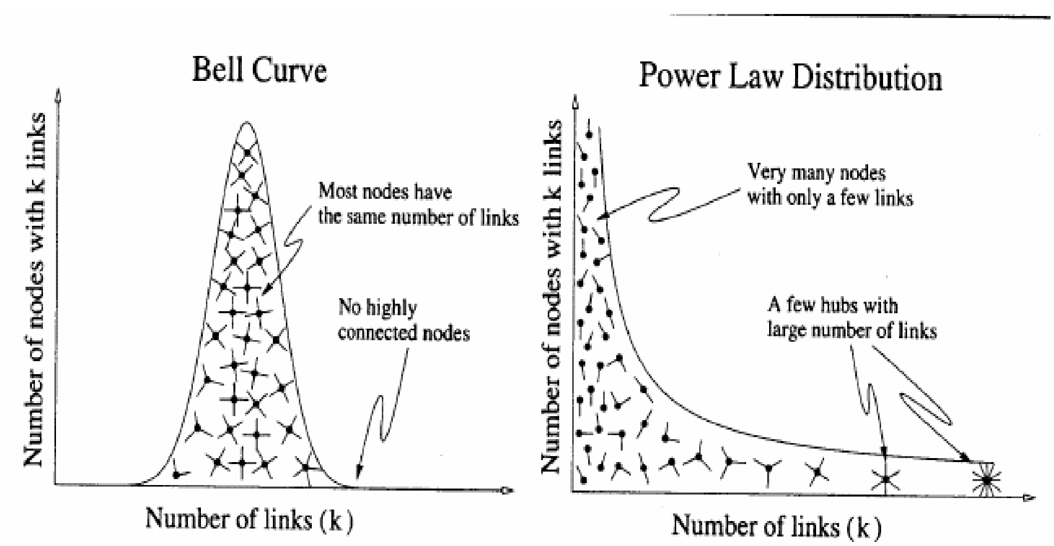

Figure 5. Bell Curve and Power Law Distribution[6]

The power law will also apply to military aircraft on the Airborne Network. Some large aircraft that act as hubs will have connectivity to a large number of nodes, each platform/node will have connectivity to a few select nodes, and some aircraft will have connectivity to only 1 or 2 other nodes. The larger aircraft will also have access to

[6] "Linked: How Everything Is Connected to Everything Else and what It Means for Business, Science, and Everyday Life", by Albert-Laszlo Barabasi, 2003

larger providers (similar to ISPs) that offer the extra information in the less frequent times it is required.

The Value of a Military Network

The goal of the military is to accomplish the mission, not to earn a profit like commercial enterprises. To accomplish the mission, the exchange of information is required between various nodes that make up COIs. The AN will interconnect COIs for the purpose of exchanging the information.

For this paper, *interconnect* means the link required to connect the nodes in the COIs. In the OSI model, interconnection would include the first four layers: physical, link, network and transport. This physical and link layers could be fiber, SATCOM, Line-Of-Sight (LOS) radio waves, etc. The network layer may be IP**.** Due to latencies and high Bit Error Rates in SATCOM and radio communications, the transport layer will require protocol gateways for applications requiring TCP. The network is responsible for the interconnect portion.

For this paper, the term *exchanging* refers to the format of data or information. The nodes comprising the COIs must use the same protocols. In the OSI model, exchange would include the session, presentation, and applications layers. The COI is responsible for the exchange of information. The COI processors, displays, software, and personnel are responsible for the exchanging of information (OSI layers 5, 6 & 7).

Dahlgren & Evans Law

Essentially a network, like most infrastructure items cannot be valued to a specific amount. The value of a network is a relative decision. This value is relative to items such as connectivity without the network, the ease of joining other networks, the performance available by other networks, and the cost of joining this network as opposed to other networks, if other options exist.

$$\mathbf{V_N = f(V(COIs), t(joining\ a\ COI), C(joining\ a\ COI), C(distance), C(complexity))}$$

$$V_N = \sum V(COI)i, \quad 1<i<20$$

By not linking network value to the total number of COIs, the network value then increases or decreases according to the value of the sum of the COIs, and the ease of entry and exit from specific COIs as dictated by mission needs. The ease of entry is directly related to the time required to join a COI and the cost of joining a COI.

The negative correlation between time and cost to join a COI leads to the increased value of a network that is based on readily adopted standards that facilitate ease of entry and exit. Adopting standards that improve interoperability to a wider community of users will greatly improve the value of a network at any given time. For instance, the

Link 16 network is proving to be very valuable to military operations, but the cost and time required for new users to join the network and to exchange new types of information can be prohibitive. As the military moves to IP networks, the cost and time required to add new participants, and the cost and time to add new types of information being transferred, will become negligible. The Airborne Network will have a fairly high initial cost, with the cost including such items as developing, purchasing and integrating the FAB-T or Joint Tactical Radio System (JTRS); as well as developing the network management system for the AN. The subsequent costs for adding new users, and gaining interoperability with terrestrial networks needs to be comparatively small.

The most valuable network

In a perfect world, there would be one network. This network would connect all COIs. The time and cost for a COI to join the network would be minimized because of the agreement between all COIs to use the same standard protocols, terminology and data formats. The amount of machine-to-machine transfers would be maximized and an in-depth study of the Human to Machine Interface would be conducted to reduce the distance and complexity penalties.

Preliminary thoughts on establishing the AN with respect to the D & E Law

In establishing the AN, we want to create an environment where all COIs can connect to each other and exchange information. We must keep in mind that very few nodes will have the funding available to take one gigantic step to the desired reality. Instead, deliberate, incremental steps will need to be taken by the nodes. The AN will be an infrastructure item and the design decisions made today will greatly influence the actions and costs required tomorrow.

When building out the AN, the following concepts should be taken into consideration:

- The most valuable COIs should be connected first to therefore maximize the operational utility per dollar invested. The valuation of a AN connection in relation to a specific mission is necessary. Each military network should be assessed a value. Each increment of the AN should be evaluated and given a value in light of the D & E Law.
- Keep the Power Law in mind when building out the AN. We would expect some nodes to participate in a number of the most valuable COIs, and therefore the Air Force should be willing to invest in these nodes to reap the greatest initial rewards/operational utility.
- The network design should attempt to maximize the commonality of protocols between nodes to ensure each node can quickly and inexpensively join additional COIs as needed.
- The incremental build out of the AN will likely necessitate the use of gateways to connect those nodes that haven't yet merged to common protocols.

- The network design should take into account any items that increase the impedance to network connectivity. Two primary impedances include items that increase the distance (i.e., mouse clicks) to gaining information, and items that increase the information overload.
- Aircraft Integration and Installation schedules dictate that building out the AN will take many years.
- Always keep in mind that the AN will be an infrastructure item. If the network is relatively easy and inexpensive to join, then new connections will be formed by COIs in ways that were never anticipated during the original design.

Summary

While the authors were not able to develop a formula that clearly shows the ROI of procuring an AN, they were able to provide guidance on 1) how not to determine the value, and 2) a new methodology for determining value. The inability to determine a specific ROI for an item like an AN is not uncommon. The AN represents an infrastructure item, and investments in such items have rarely been based on a ROI calculation, but instead have been based on a need to have this basic capability to enable functions that facilitate key activities for society. This has been shown by how quickly society comes to a halt during a natural disaster when many utilities fail and roads are not accessible.

While a specific return on investment cannot be determined, the need to determine the ordinal value of the network solution enabling various COIs should be attempted. This type of determination will likely require some form of modeling & simulation to show the relative impacts of adding networking capability to specific nodes that participate in various operational scenarios. The Air Force can then network enable those COIs with the highest operational impact and that are the least costly to join and can be joined in the shortest timeframe. This thought process follows the DoD's focus on Capabilities Based Planning. Organizing the deployment of an AN according to capabilities should allow the Air Force to gain the most operational utility per dollar invested. This type of consideration will be especially important during these times of tight budgets. While the formulas presented by Sarnoff, Metcalf and Reed may have applicability to some areas of the economy, these formulas do not aid the Air Force in determining the value of an AN or the possible methodology to invest limited funding in an AN to optimize the operational impact. Additionally, Sarnoff, Metcalf, and Reed fail to consider the complexity penalty that occurs when human beings, or networks, become overloaded with data.

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