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Developing a Framework for Exploring Clustering Coefficient to Evaluate System Coupling

Topics
C2 Technologies & Systems
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John W. Dahlgren

The MITRE Corporation
903 Gateway Blvd, Suite 200
Hampton, Va 23666
757-825-8529
Dahlgren@mitre.org

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Abstract

This paper will discuss the concept of the Clustering Coefficient as used with regard to the connectivity between people and/or organizations. Using a hypothetical group of people (as would be found in a small project team) as an example, this paper will determine a possible best range for the Coupling Coefficient to resolve the optimal number of tight and loose connections. The concept of diminishing marginal returns and the tradeoff between tight and loose connections will be examined to determine how tight connections may actually destroy options on exchanging information with other people, and thus lower the value of the organization. The concept of the Coupling Coefficient will then be applied to discuss the concept of Loose Coupling as is often applied to hardware and software systems, or systems of systems. The goal of the aforementioned section will be to determine a framework with which to examine the level of coupling between subsystems in a system of systems, and then determine to what degree a system is coupled, with possible implications to the difficulty and costs of spirally developing the subsystems. Coupling to standards will be presented as analogous to limiting the tight connections between people.

Introduction: In looking at valuing networks and applying this concept to organizational design, the concept of clustering and the Clustering Coefficient became apparent. Unfortunately, while the concept is discussed, a formula to readily apply to an organization or an actual network is rarely found. Additionally, the application of the Clustering Coefficient is discussed cursorily but not deeply investigated. This paper uses a previously developed method for calculating the Clustering Coefficient and applies it to a hypothetical group to determine the levels of a Clustering Coefficient that aid or hinder group performance. This author believes that social networking theory and systems engineering concepts can be closely linked. As such, this paper attempts to move past the idea of a Clustering Coefficient to provide a possible method with which to evaluate loose coupling between technical systems. The term Coupling Coefficient is used to represent the degree of coupling between technical systems. The author then provides possible formulas to use in determining the Coupling Coefficient for technical systems.

Clustering: Clustering is a measure, or at least a heuristic, to define the level of connectivity between a group of people. The Clustering Coefficient (CC) is the measure of this level of connectivity. As described in *Linked: How Everything is Connected to Everything Else and What it Means for Business, Science, and Everyday Life (Linked)*, when 4 people are all closely connected, the CC = 1.0 (Barabási, 2002). Essentially:

CC = number of close links/number of possible close links
Number of possible close links = N(N-1)/2

For example, *Linked* says that if there are 4 people, there are 6 possible close links. Some readers may confuse this with what is commonly referred to as the "N(N-1), or the N^2 problem". This problem is how people describe the pre-networking challenge that occurred when the DoD tried to have all of the nodes in a certain mission area connect to

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all the other nodes in that mission area. The N(N-1) equation was based on the use of half-duplex radios and the need to be able to transmit and receive at the same time. In *Linked* they show only 6 links between 4 nodes because they appear to assume full duplex links. This explains why the above formula divides the N(N-1) by 2.

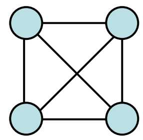

Figure 1. Linkage between 4 Close Friends

From the above example, if each of the 4 people are all close friends, then CC = 6/6 = 1.0. However, in reality not everyone will be close friends. If only 4 of those links were considered to be among close friends, then the CC = 4/6 = .667. Generally speaking, many people would look at these examples and believe that having a CC = 1.0 is optimal. Surprisingly, that is not the case. When everyone in a group is very close to each other, they primarily exchange information with each other, limiting their information sources and the knowledge to which the group has access. As pointed out in *Linked* and *The Agile Organization: From Informal Networks to Complex Effects and Agility* it is optimal to have some closeness within a group along with having what are called weak connections to outside groups, thereby making more information available to more people. *Linked* related this to job searches, pointing out that most people do not learn about job openings from their close friends, but rather from friends-of-friends. The mixture of a close knit group of people along with weaker outside links to other groups is referred to as a Small World Network.

Optimal Clustering Coefficient

While various sources have discussed the CC, the author has yet to find one that deeply discusses how to optimize network performance to have a Small World Network that takes into account:

- ❖ How the formula for CC can be amended to take into account the optimal range of tight connections.
- ❖ How the formula for CC can be amended to take into account the benefits of medium and weak connections.
- ❖ How the answers to the CC and the above items relate to the survivability of a Small World Network.
- ❖ How a formula can evaluate the gradual degradation of performance as various links are removed in a Small World Network.

The next challenge is to determine the optimal CC, or at least a CC range, needed to provide an optimal Small World Network as judged by performance. Table 1 below shows the range of CC values for the number of close connections in a group of 4 people.

Close	**Clustering**	**Maximum #**	**Average # of**	**Resiliency of**

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Connections	Coefficient	of Hops	Hops	Network
1	.167	Undefined	Undefined	0
2	.333	Undefined	Undefined	0
3	.5	2	1.5	Minimal to 0
4	.667	2	1.33	Good
5	.833	2	1.17	Best
6	1.0	1	1	Good to Avg

Table 1. Range of Clustering Coefficient Values

Table 1 introduces the concept of network resiliency. For this paper, resiliency is defined as the combination of the percentage of links that need to be destroyed to harm the Small World Network and still have connections available for outside connections. In this way resiliency relates to keeping the immediate group connected to each other and to the outside world. Further research may discuss the time frame in which a Small World Network can be separated from the larger network before experiencing significant degradation in performance.

We have already stated that in a group of 4 people, the odds are that they will not all be close friends, and that according to the Small World Networking Theory it is not optimal for them to all be close friends. By reviewing Table 1 we can intuitively consider that a network having only 1 or 2 close connections will eliminate the chance for strong connectivity between the team no matter how many hops the information must traverse, thereby eliminating any chance for good performance by a team of 4 people. That leaves us to consider the relative merits of having 3-5 close connections. Evaluating this situation may require the determination of the greatest number of hops required for information to transfer between the two most disconnected links, and the average number of hops required for information to transfer between any two people in the network.

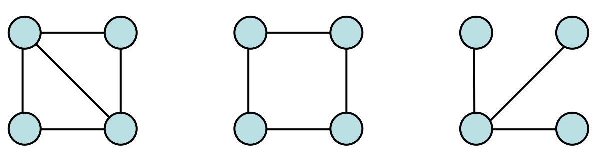

Figure 2. Diagrams of 5, 4, and 3 connections

As shown in Figure 2, going below 3 connections for a group of 4 people means the group is not fully connected. The diagram of 3 connections also shows that the network has collapsed into a star or a serial connection between the nodes. Both of these constructs are very fragile since the loss of the hub means network disintegration. The diagram of 4 connections shows that no node must act as a hub, and that the network would need to lose 2 connections (50%) to leave any node unconnected. The diagram of 5 connections appears to have the most resiliency since it would take the loss of at least 2 connections, and sometimes 3 connections, to leave any node unconnected. In this case eliminating the correct 2 connections (40%) is still all that is required to start harming the network, although in some cases it would take the removal of 3 connections (60%).

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From a resiliency standpoint, there is some benefit to the extra connection (5) if the threat to the network is random and statistically based. Against a knowledgeable enemy there may be no benefit to 5 connections.

While the above discussion relates to the resiliency of the internal network nodes to each other, it fails to take into account connectivity to the outside world. When viewing the tightest connectivity between the 4 nodes, it is apparent that each node can handle up to 3 tight connections. A second look at the 5-connection diagram reveals that 2 nodes would still have the capacity for an additional connection to the outside world, while analysis of the 4-connection diagram reveals that all 4 nodes have the capacity for 1 additional tight connection to the outside world. There appears to be a tradeoff between additional tight connections between the nodes of the group and the opportunity cost of having connections to the outside world.

Diminishing Marginal Returns on the Number of Connections

Many discussions on networks imply that more connections are better. This thought seems to disagree with the concept of diminishing marginal returns. While every person reacts differently, each person most likely has a maximum number of other people with which they can maintain close contact. For each of us there is a point where we not only receive diminishing returns by attempting to maintain an additional close connection (with all of the time and effort involved), but also a point where an additional connection provides negative returns. A person has reached the point of diminishing marginal returns when the value added by the new connection is less than the value added by the last connection. A person has reached a point of negative returns when the new connection lowers the total information content value, possibly because this new connection takes time away from the old connections. On the other hand, each person can most likely maintain far more weak connections than they can one close connection. Possibly when a person reaches diminishing marginal returns on their total Small World Network value, and definitely when a person reaches negative marginal returns on their close connections sub-network, the person should consider which close connections to sever or at least weaken to optimize the value of the close sub-network and the overall Small World Network. Two key assumptions of the economic theory of marginal and total returns are that there are no second order effects of adding new connections and that each connection has the same value and cost.

Diminishing Marginal Return: $\Delta V_n < \Delta V_{n-1}$

Negative Returns: $\text{Total Value (TV)}_n < TV_{n-1}$

Real Options and Network Connectivity

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Each connection to a node represents an option that the node operator, and the network overall, can leverage when needed. Therefore the strength of each connection should be reviewed from the standpoint of diminishing marginal returns and diminishing total returns. Looking back at the 3, 4, and 5 connection networks in Figure 2, we should now consider the alternatives to substituting a close connection for a weak connection or for multiple weak connections. Adding strong connections to a node impacts the number of weak connections that node can support and the network can utilize. The network topology should be reviewed to take into account the likely increase in value of adding multiple weak connections in lieu of some strong connections. This evaluation should take place at the point where the addition of another tight node shows a decreasing marginal utility.

A review of the resiliency of the networks has shown that the 3-connection network has little survivability; that network should be removed from consideration. The discussion now proceeds to evaluating the relative merits of moving from each of the 4-5-6 connection networks. These networks are very comparable in the average number of hops and the greatest number of hops between any two nodes. The 6-connection network has a maximum and average hop length of 1, clearly the lowest number of any network choice. On the other hand, the Small World theory has shown that having all nodes tightly linked lessens the network's resiliency due to a lack of outside connections. Additionally, there is a cost for each of those network connections.

So far basing our analysis on resiliency, average hops, maximum hops, and cost of network design shows that the optimal network will be either the 4 or 5 connection network. The choice now comes down to which network provides the greatest number of possible weak connections. As previously discussed, it appears that each node can accommodate 3 tight connections. In this case the 4-connection network offers the chance for weak connections attached to all 4 nodes. While the Replacement Coefficient for weak connections compared to strong connections has not been determined, the author expects this coefficient to be $\geq$ 2.0. In applying the estimate of being able to replace 1 tight connection with 2 weak connections, the diagram with 5 tight connections means that 2 nodes can each support up to 2 outside connections, giving the group 4 weak connections to the outside world. A similar analysis of the 4-connection network shows that each node can provide 2 connections to the outside world, giving the group 8 connections to the outside world. Each of those outside connections offers a Real Option (RO) the group can exercise as needed to gain information from other groups. Additionally, the network's resiliency increases with a weak connection (as opposed to no connection) because the weak connection offers the chance to still connect between its own nodes by simply taking more hops than required with tight connections.

Quality of Information

While the previous discussion focused on the number of connections and differentiated between whether those connections are tight, medium, or loose, another consideration is the quality of information passed over each connection. The quality of information determines whether the connection, independent of its tightness rating, has a positive or

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negative value. This might also relate to how teams are developed and employed. For instance, some people are more outgoing and extroverted than others. Those extroverts may or may not have the highest quality of information, whereas the situation can often exist where an introverted person has a very high quality of information but lacks the personality to readily share that information. In these cases, managers should try to tightly link a person with a high quality of information with a more extroverted person to thereby maximize the value of the network for those people that are closely connected and those that have a number of loose connections. Table 2 shows the relative value of tight and loose connections as the quality of the information changes. Essentially, a high quality of information is always optimal, and a low quality of information is always detrimental. While a high quality of information is good when nodes are tightly connected, recall that the value of each tight connection must be compared to the value of a greater number of loose connections. In the case where information quality is high, having loose connections is of greater value than having tight connections because this information can be shared with a greater number of nodes and can have a greater influence on the enterprise's value. When information quality is low, having only tight connections is very detrimental because the tight connections limit outside influences, giving the low quality of information greater influence on that cluster.

	Tight Connection	**Loose Connection**
High Quality Information	**+**	**++**
Low Quality Information	**--**	**-**

Table 2. Relative Value of Connection

Relationship to the Clustering Coefficient (CC)

The prior analysis can be done via simple diagrams and calculations for a small network of only 4 nodes. The challenge now becomes how to apply the CC to larger networks. Software exists to analyze networks by inputting information on who talks to whom, and can provide a calculation for a Clustering Coefficient. The challenge now becomes determining how to use this information. From the above example the author has developed the hypothesis that a network will have good performance if:

$$.6 \geq CC \geq .83$$

A CC below .6 appears to indicate that the network topology offers the chance for too few close connections for the Small World Network to operate efficiently, and going below a CC = .6 risks the network collapsing into a star. A CC greater than .83 (may need to be lower for larger networks) appears to be the point at which the network may have too many close connections and has lost the RO provided by having more weak connections that link to other information sources and the resiliency that comes with a Small World Network.

The challenge now becomes whether a formula can be developed to aid in the use of the above heuristic to judge a network's topology. A key concern of any formula or heuristic

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is to ensure that a process, system, or person is not measured according to a single metric. A better way to evaluate such a formula or situation is to develop a few opposing formulas or metrics that merge into a framework with which to evaluate a situation. Bringing the previous discussion on options into account, a revised formula for the Clustering Coefficient and Optimal Network Design might yield:

Optimal Network Design Π (union of)
$$.6 \geq CC \geq .83$$
$$Design_2 > \#\text{ of Weak Links than } Design_1$$
CC = number of close links/ number of possible close links
Number of possible close links = N(N-1)/2

Relationship to Loose Coupling and Platforming

The definition and a formula for Loose Coupling (LC) have been very difficult to develop. In some instances, just making the intellectual distinction between tight and loose coupling is difficult. Previous discussions on LC have often implied that any tight coupling can be bad for the overall system. To the contrary, some tight coupling can prove to be good. For instance, relating back to research performed by Konstantinos Kalligeros in his PhD dissertation, platforming (standardization) can be both positive and negative (Kalligeros, 2006).

Platform Design can provide:

- Managerial flexibility
- Faster/cheaper deployment of new variants or system increments
- Modularity of design and use, leading to operational flexibility
- Interface standardization, thus providing interchangeability
- Learning organization, focused on innovation

Platform Design can also have some possible negative impacts:

- Strategic commitment and possible sub-optimality of long-term design
- Locking-in with expertise and a given supply chain
- Dominant standards that subsequently limit innovation
- Not enough “extent” for changing future requirements
- “Local” suboptimality

Therefore, there is likely an existing range of platforming opportunities that can provide options for system design. This author hypothesizes that the use of Design Structure Matrices (DSM) can be developed for technical systems and should be evaluated in much the same way that a network engineer or sociologist should evaluate the Clustering Coefficient.

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For example, let us apply this concept to a system that has 30 subsystems. A system of 30 subsystems would have 435 possible connections between subsystems. The question then becomes whether the heuristic discussed earlier for human and communications networks applies here. It is highly unlikely that a good systems engineer would then want to have 261 to 361 (.6 to .83) subsystems tightly linked together. This is still a level of integration and complexity that will make system evolution very difficult. On the other hand, the concept of coupling may relate more to ensuring that each system is connected to at least 1 other system in an electronic or mechanical manner. The author contends that systems that only connect via a "sneaker net" are not really connected at all. Therefore, a loosely coupled system will have each subsystem technically connected in some manner to at least one other subsystem.

The Design Structure Matrix

A Design Structure Matrix (DSM) is a compact representation of a digraph (directed graph) that depicts the relationships among the components in a system (DSM Web Site, 2006). Systems engineers use DSMs to illustrate relationships among subsystems.

The rows and columns in the DSM are analogous to nodes in the digraph and correspond to system components. The cells in the matrix are analogous to edges in the digraph and represent the relationships among the system components. As in a digraph, the relationships tracked by a DSM are directional. Thus the relationship of component A to component B is distinct from the relationship of component B to component A.

This study employs DSMs to articulate how changes made to components affect other components in a system. The relationships in the DSMs indicate whether a given component will require modification if another specified component is upgraded. These relationships are stated as dependencies. Figure 3 shows the three possible types of dependency relationships.

<table>
<tr><th colspan="4">Three Configurations that Characterize a System</th></tr>
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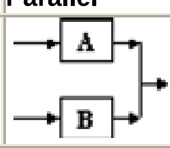
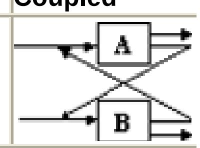
<tr><td>Graph Representation</td><td></td><td></td><td></td></tr>
<tr><td>DSM Representation</td>
<td><table><tr><td></td><td>A</td><td>B</td></tr><tr><td>A</td><td></td><td></td></tr><tr><td>B</td><td></td><td></td></tr></table></td>
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Figure 3. DSM Component Relationships (DSM Web Site, 2006)

In the first relationship depicted in Figure 3 (parallel), changes to the system components do not interact with one another. Thus component B is independent of component A (and vice versa) with regard to modifications. Upgrades to either

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component can be made independently. In the sequential (also known as dependent) relationship, changes to one component require modifications to another component in order to maintain a working system. The figure depicts that component B is dependent upon component A. Thus, if component A is upgraded, then component B will require modifications to keep the system operational. Finally, in the coupled relationship, components A and B are interdependent and therefore coupled.

Figure 4 depicts a DSM for a generalized connectivity between a satellite terminal to satellite to satellite terminal. While some users of DSMs insert a "1" or an "X" in the boxes to indicate a relationship between two subsystems, this author has chosen to use an "H" to indicate a high degree of coupling, an "M" to indicate a medium degree of coupling, and an "L" to indicate a low degree of coupling. Each of these linkages, or couplings, indicate an increased level of complexity since each relationship will impact the initial design and any efforts to upgrade one of the subsystems since that will impact the other subsystem as well. These linkages are similar to linkages between nodes in the social network discussed earlier in this paper. Tight couplings between subsystems can lead to customized design rules between each of the subsystems, making the total system very tightly coupled and very difficult to design, maintain, and upgrade. Additionally, tight couples between components or subsystems are similar to the tight couples in a social network. Each subsystem has a theoretical limit on the number of other subsystems with which it can maintain tight couples, and thus may limit any additional couples, whether tight, medium, or low, with other subsystems.

		1	2	3	4	5	6	7	8	9
Baseband -- User 1	1		L	H						H
Input Port -- User 1	2			H						
Terminal -- User 1	3	H	H		M	H	L			
Uplink Channel -- User 1	4			H		H	M			
Satellite Communications Payload	5			M	L		L			
Downlink Channel -- User 2	6			M	M	H				
Terminal -- User 2	7			H	L	H	M		H	H
Output Port -- User 2	8							H		
Baseband -- User 2	9	H		M				H	L	

Figure 4. Generalized Satellite Terminal – Satellite – Terminal DSM

Standards and Interfaces

While the previous discussion focused on subsystems being coupled to each other, the system should also be evaluated by the number of standard interfaces used. Standards, especially those that the consumer base (not just this customer) has most readily accepted, would be analogous to a strong connection. For instance, the linkage between computer systems and networks should then be evaluated at each of the 7 layers of the Operational System Interconnect (OSI) model. Therefore, each subsystem could have up to 7 strong connections to standards but still be loosely coupled to other subsystems since changes in

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one subsystem that still maintain coupling to the interface standards will not impact the other subsystems. Of course a subsystem can support multiple standards. The benefit of coupling to standards means that the degrees of complexity for a system are decreased.

The OSI stack provides a somewhat idealized linkage to standards. Many systems of systems are built with Commercial Off The Shelf (COTS) products. Those products are often built to commercially accepted standards. Frequently a commercial product will gain significant market share and come to dominate the market place. As designers choose to platform on specific COTS products, the overall system can unfortunately become tightly coupled to the product line. This is obviously good for the provider of the COTS products because now the consumers and the system-of-system designers/owners will need to upgrade at various intervals, often less than 5 years in time, to maintain interoperability with the given COTS product line. Therefore, while platforming on the COTS products appeared to provide the system with the option to leverage the research & development efforts of COTS providers, the ability to continually exercise that option has a cost related to the upgrade cycle. Users of such COTS products can gain back flexibility and decrease the level of complexity by developing processes to possibly skip some upgrades and only exercise an option on every other upgrade to the COTS product. In essence, the revised upgrade process decreases the lifetime cost of exercising the options and increases the net value of the option for the user.

Coupling Coefficient

Now, let us revisit the earlier discussion on the Coupling Coefficient. That discussion really pertained to whether the nodes exchanged information often, sometimes, or not at all. Having common standards (a common language, transmission protocols, computer applications, encryption techniques, etc.) can facilitate this connectivity. A possible error in any discussions related to coupling is the assumption that users and/or designers intended these couplings to aid the systems in exchanging information or at least working together. In some cases the couplings may be a design error. The Coupling Coefficient for hardware and software systems should really focus on the ability of the systems to exchange information or work together, relate to the coupling to common standards, and relate to the upgrade cycle of COTS products used in the overall system design. *Therefore, the Coupling Coefficient formula for hardware and software should relate to the tightness of coupling for each system to other systems, to standards, and to upgrade cycles. For computer networks, the coupling to standards would be evaluated at each layer of the OSI stack if each layer is required to exchange information.* The use of standards has the possibility to greatly decrease the number of tight couplings in a system of systems.

Therefore, a system can be tightly coupled to another system if the coupling is accomplished using a non-standard linkage. Systems are loosely coupled to each other if they are linked using a standard that is readily available to and used by the consumer base for this product. Therefore, systems do not necessarily need to use standards linked directly to COTS products. Ideally, each of the subsystems that must exchange information, or are even expected to exchange information, should be linked at each level

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of the OSI stack to a standard that is readily available to and used by the consumer base. Readers should note that a focus on the use of COTS standards and their products can actually cause a system to be tightly coupled to a product line and the subsequent development cycle.

Determining a Formula for Coupling Coefficient

A formula for a Coupling Coefficient needs to include a variety of factors. Starting with the DSM, designers can see how many close connections a system or system-of-systems will have. Drawing on the previous explanation of the Clustering Coefficient, the Coupling Coefficient needs to start with the following:

$$\text{Coupling Coefficient} = \sum_{\substack{i=1\\i=1}}^{n} S_i S_j \Big/ \text{number of possible tight couplings}$$

The use of standards can often decrease the levels of complexity, but may also raise the levels if the standards are not used judiciously. Using a computer network and the OSI stack as an example, a poorly designed system that has 30 subsystems could end up with a worst case of (30X29/2)7 = 3,045 tight couplings. While possible, that level of error in engineering design is (hopefully) unlikely. On the other hand, the optimal solution using the OSI stack and common standards means that the total system of systems might be tightly coupled to only 7 standards. This would appear to be a perfect use of standards.

$$\text{Coupling Coefficient} = \sum_{i=1}^{7} OSI_i \left[\sum_{\substack{i=1\\i=1}}^{n} S_i S_j \right] \Big/ \text{number of possible tight couplings}$$

As previously discussed, the use of COTS products can provide the designers with an excellent option to utilize commercially developed research and development. The use of COTS can also force system owners and sustainers to deal with required upgrade cycles. These upgrade cycles must be considered when determining the Coupling Coefficient for a system or system-of-systems. While no definite formula has been developed for the linkage to COTS product upgrades, this author hypothesizes that the tightness of the coupling decreases with the years between required system upgrades. Therefore, the portion of the Coupling Coefficient formula may equate to

$$\text{COTS Portion of Coupling Coefficient} = \sum_{\substack{i=1\\i=1}}^{n} S_{(COTS)i} S_{(COTS)j} \,/\text{Years to upgrade}$$

Given the above formulas, the total Coupling Coefficient is tied to the system to system linkages, the use of standards, and the use of COTS products. While the DSM presented in Figure 4 only shows technical subsystems, a DSM can be adjusted to show standards used. Evaluating the DSM according to standards used for each subsystem will indicate whether designers have judiciously used standards to tightly couple subsystems to a group of accepted standards and thus decrease the number of total tight couples. Given the example of the computer network and the OSI stack, the number of tight couplings

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can either greatly explode or greatly decrease to only a handful. While engineers often refer to standards, in the computer and networking area COTS products can become the de facto standard. As such, the system, or subsystems within, can become tightly coupled to the COTS product line. Engineers and sustainers have the opportunity to evaluate this tight coupling and the upgrade cycle to determine if some upgrades can be skipped, thereby diminishing the impact of tightly coupling to COTS products, while still be additive to the overall Coupling Coefficient.

Summary

It appears that the concept of the Coupling Coefficient can be applied to physical networks in a manner that is similar to how the Clustering Coefficient can be applied to human networks. An example of applying the Clustering Coefficient to a network of 4 nodes was used to evaluate the impact of tight and loose connections on the resiliency of a Small World Network. The need to decrease tight couplings was related to opening up Real Options (RO) for the network participants to exercise to gain information from outside sources, and that the increase in tight connections should be stopped at the point of diminishing marginal returns. At that point future connections should be loose instead of tight, and should be used to connect to other Small World Networks. For technical systems the concept of a Coupling Coefficient was presented. The Coupling Coefficient relates to the number of subsystems that are directly connected, to the use of standards in the system design, and the impact of using COTS products. The use of standards represents opening up each of the subsystems in an information exchange to freely evolve as needed within the boundaries of still working according to the technical standard. This use of standards provides the opportunity for sustainers to upgrade a system as technology provides new solutions. COTS products present the option to use product upgrades developed for many customers, but also presents a challenge of maintaining a minimally acceptable interoperability with new upgrades to those COTS products, whether the customer desires these upgrades or not. While much of this paper focuses on determining the tight couplings and trying to decrease the number, some tight couplings will still need to be maintained, if even only to technical standards. Here the number of required tight couplings is linked to the degrees of complexity for the systems. Reducing the total number of tight couplings and the number of different types of tight couplings will decrease the complexity of the system.

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