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Keyword Analysis of Command and Control-Related Science and Technology Efforts of the United States Department of Defense

Topics:
(1): Concepts, Theory and Policy
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Corinne Kramer
Institute for Defense Analyses
4850 Mark Center Drive
Alexandria, VA 22311
USA
+1-703-578-2805
ckramer@ida.org

M. S. Vassiliou
Institute for Defense Analyses
4850 Mark Center Drive
Alexandria, VA 22311
USA
+1-703-887-8189
+1-703-845-4385
mvassili@ida.org

Jonathan R. Agre
Institute for Defense Analyses
4850 Mark Center Drive
Alexandria, VA 22311
USA
+1-703-933-6522
jagre@ida.org

Point of Contact:

M. S. Vassiliou
Institute for Defense Analyses
4850 Mark Center Drive
Alexandria, VA 22311
USA
+1-703-887-8189
+1-703-845-4385
mvassili@ida.org

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Abstract

Science and Technology (S&T) efforts within the Department of Defense (DoD) that relate to Command and Control (C2) include a wide range of activities, from communications to human learning to information organization and decision-making. We have compiled an extensive database of DoD-funded C2-related programs to assess the alignment of S&T efforts with the goals outlined in the DoD's C2 Strategic Plan. We collected data from the Defense Technical Information Center (DTIC) Research, Development, Test and Evaluation (RDT&E) database, spanning funded programs from basic research to advanced technology development. We further categorized the programs by technical area, and by applicable Joint Capability Area (JCA). We present the results in terms of funding levels for fiscal years 2010-2012 for each of the categories and provide a mapping between the JCAs and the technical areas. Our analysis shows roughly balanced funding across the areas, with an emphasis in the technical areas of situational awareness and network architecture. With some adjustments, we believe the S&T efforts appropriately reflect the infrastructure currently needed by warfighters and commanders, and provide a basis upon which future, higher-level C2 developments may be made.

Introduction

The role of Command and Control (C2) in military operations is under transformation. Rapidly developing technology is enabling communications and development of situational awareness in ways that were previously not possible. The United States Department of Defense (DoD) has a mandate to provide effective and efficient Command and Control capabilities to its warfighters and has committed substantial funding towards this goal. Within this collection of C2-related programs, it is desired to examine the programs devoted to Research, Development, Test and Evaluation (RDT&E) and specifically those programs addressing emerging Science and Technology (S&T) needs for C2. In addition, we would like to identify how these programs are supporting the objectives put forth in the DoD *C2 Strategic Plan* [1] and to identify the specific C2-oriented technologies being developed.

In this paper, we consider the full scope of topics covered within funded programs relating to a broad definition of C2 that includes the areas of Command, Control, Communications, Computing, Intelligence, Surveillance and Reconnaissance (C4ISR). We use programmatic information from the "Defense Technical Information Center's (DTIC) Research and Development Descriptive Summaries (RDDS)" budget justification sheets for 2012 [2]. We analyze all identified C2-related programs categorized under RDT&E funding to determine the balance of effort (quantity and fiscal levels) devoted to C4ISR RDT&E. We further analyze the subset of C4ISR programs that are science and technology (S&T) programs from the subset of RDT&E programs focused on S&T, which covers basic research to advanced technology development (classified as 6.1 to 6.3 budget activity levels). We assess where these support the DoD *C2 Strategic Plan* [1], and which C2-related technologies are addressed.

In order to address how the warfighter's C2 needs are being met we have used the Joint Capability Areas (JCAs) to associate specific military capabilities to each C4ISR program. The JCAs are a framework which functionally groups similar military capabilities into nine top-level areas: Force Application, C2, Netcentric, Battlespace Awareness, Protection, Logistics, Force Support, Building Partnerships, and Corporate Management & Support [3]. These top-level JCAs are further broken down into sub-levels. The Joint Capability Areas relating to our view of the C4ISR topics include "C2," "Netcentric," "Building Partnerships," and "Battlespace Awareness" as shown in Figure 1. As can be seen in the figure, we view the C2 JCA as the core of the relevant areas, but also include JCAs up to and including C4ISR in our analysis. Throughout the analysis we utilized *C2, Netcentric, Building Partnerships and Battlespace Awareness* as "Level 1 JCAs". One level of granularity below that (for example, *C2-Organize*) is considered a "Level 2 JCA."

The programs and their research topics supporting these JCAs are considered to be essential to implementing the wide range of command and control functions necessary for the warfighter. Below, we discuss how the objectives of the *C2 Strategic Plan* additionally support this view.

For the purpose of ascertaining alignment between the funded research efforts and the DoD's vision of C2 we note that the *C2 Strategic Plan* [1] outlines five objectives:

1. Objective 1, *to provide the capabilities necessary to effectively support organizing command structure and forces, understand situations, plan and decide upon courses of action, and direct and monitor execution across the range of DoD operations,* is captured in the C2 JCAs.
2. Objective 2, *to enable military forces and mission partners to conduct integrated operations across the range of DoD operations at all echelons of command*, is broader than, but encompasses the Building Partnerships JCAs.
3. Objective 3, *to maximize assured sharing of information and services and synchronized implementation of collaborative C2 capabilities,* encompasses the Netcentric JCAs.
4. Objective 4 is *to optimize C2 capability investments across the range of DoD operations*, i.e. to provide achievement of the goals with financial constraints.
5. Objective 5 is *to achieve agile and responsive development, acquisition, fielding, and sustainment of C2 capabilities across the Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities* (*DOTMLPF) spectrum*, or to utilize an agile process.

We employed a digital survey technique based on keyword search to identify the programs supporting each of the C4ISR-related JCAs. We also included Battlespace Awareness (which was not explicitly called out in the Strategic Plan, but which supports C2 activities at many levels). Additionally, we used the 2012 budget information for each of the programs to inform our understanding of support for Objective 4. We are unable in the scope of this analysis to assess Objective 5.

We collected programmatic information from the DTIC RDDS R-2 budget justification sheets for 2012 [2] in the form of Extensible Markup Language (XML) files. We developed Python scripts to

process the XML files and placed the extracted data in Microsoft Excel and Access files for further analysis. There were over 800 program elements included in the database. Program elements were further broken down into programs, of which there were 6,714. Descriptive items in the available 2012 data include program element number, program element title, mission description, program title, program description, prior year (2010) accomplishments, current year activities (2011), and future year plans (2012) as well as budget information for each of the three years. As our main area of interest is in early research S&T activities, we focused our analysis on budget activity levels 1-3. The total funding for 2012, 2011 and 2010 was $12.1B, $11.8B, and $12.3B respectively.

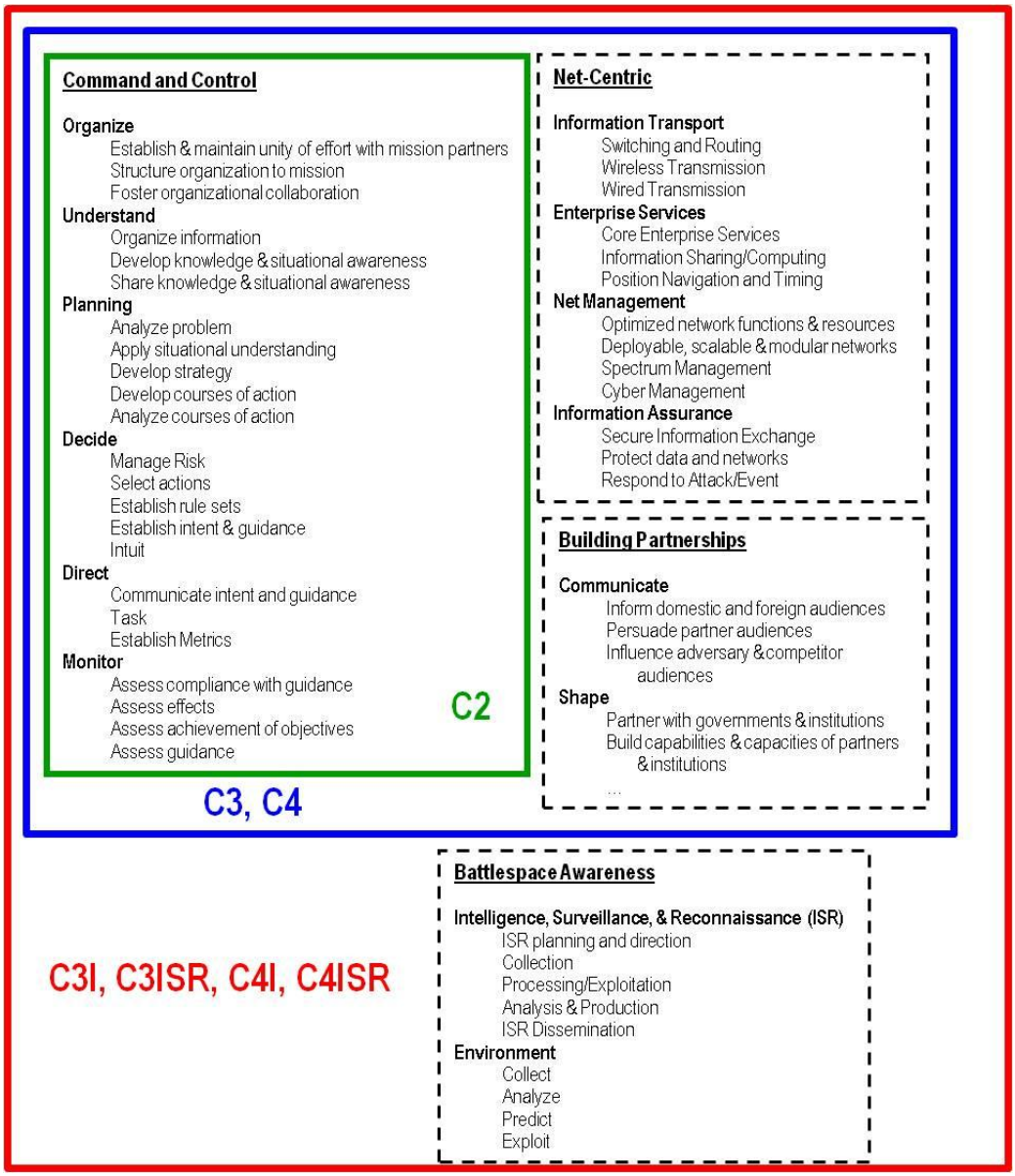

Figure 1 The Joint Capability Areas, as defined by the Joint Staff. We use an expansive view of C2 for the purpose of this analysis.

We used the programmatic information contained in the program description, accomplishments, activities and plans to categorize the programs in a variety of ways in an attempt to

identify the Department's focus, direction, and potential gaps across the set of S&T C4ISR programs. We first identified the capabilities and technical areas which support command and control and then performed keyword searches on these capability or technical areas over the programmatic information to select the relevant programs.

Conclusions can be difficult to draw from the breakdown of programs for a number of reasons. One is that there is not a clear boundary between many of the technical areas. Secondly, programs can and should be identified in multiple technical areas, as their mission may be broad. Because of this, the funding values associated with each category include redundancy between programs. Below, we discuss the methodology, conclusions and limitations of our analysis of the DoD effort to provide the S&T necessary to modernize C2 for the warfighter and commander.

Analysis

Methodology

We utilized keyword analysis to identify and then quantify the level of effort in terms of number of programs, and funding, in each of three different categorization schemes: Level 1 JCAs, Level 2 JCAs, and C2-Technology Areas. We would like to emphasize that this is not a statistical analysis, but rather an attempt to directly quantify the distribution of effort, based on subjective categorization schemes. We iterated on several different categorization schemes before identifying what we believe are appropriate methods of distinguishing the programs. The first two schemes described were derived from the JCAs, and can be classified as top-down. These categories enabled identification of the goals that program managers and decision-makers intend their research to meet. The first scheme used low resolution and consisted of the Level 1 JCAs: C2, Netcentric, Battlespace Awareness and Building Partnerships. The second scheme increased the resolution and used each of the Level 2 subcategories of the JCAs. In this analysis, we refer to these schemes as *JCA Levels 1* and *2*, respectively.

We then used our separate analysis of current trends in C2/C4ISR research *[4]*, as well as the subject matter identified in the database as a whole, to identify the broad technical areas of research and development in support of C2. Our broad view of topics related to Command and Control identified the following technical areas:

- Decision support – pertaining to the overall specific decision support tools and theory of decision making
- Planning – specific focus on the planning process within the decision process
- System Architecture – design and analysis of combined Hardware/software systems
- Network Architecture – focus on the networking and communication aspects

- Organization Architecture – design and analysis of the types of C2 organizations (e.g., edge, distributed, hierarchical, etc.)
- Collaboration – focus on organizational and multinational cooperation
- Information Sharing – focus on information sharing aspects of collaboration
- Situation Awareness – methods of obtaining situation awareness and developing a Common Operating Picture
- Interoperability – standards and techniques to achieve interoperable systems at syntactic and semantic levels
- Intelligence Analysis – specific design and analysis of intelligence processing

This third classification scheme can be described as "bottom-up," as it captures the underlying technologies being developed. Technical keywords were based on these definitions of broad technical areas.

We also identified a mapping (not one-to-one) between the technical areas and the top-down strategic "goals". This process enabled a direct comparison between the technical goals that the programs may actually be addressing (as identified by technical area), and those capabilities that the programs are intended or believed to be meeting (as identified by JCA). Table 1 through Table 3 illustrates the categories and the keywords used for the three categorization schemes and their analyses. Finally, we utilized several other keyword searches to investigate the research program focus on certain trends that are believed by the C2 community to be vital and/or prevalent, such as commercial smart phone adoption.

While an electronic keyword search has limitations, we believe we have produced a reasonable estimate of the funding and number of programs in each topic[1]. Overlap of the topics is possible, however, due to the intertwined nature of such research efforts. Via each of the classification schemes, we identified a different absolute number of programs and dollars (with no overlap). Of the 6714 programs, 2,365 were in the budget activity levels 1-3. Of those, we identified 263 (11.1%) of the programs as meeting the C4ISR JCA Level 1 goals. We identified 471 (19.9%) of the programs as meeting the C4ISR JCA Level 2 goals and 705 (29.8%) as addressing any of the C4ISR technical areas. The JCA Level 1 search identified 14.1% (2012), 15.0 % (2011) and 13.0 % (2010) of possible funding dollars, JCA Level 2 identified 28.4% and the technical areas identified 41.1 % (2012), 42.1% (2011), and 38.1 % (2010).

[1] We performed extensive sampling and hand-checking to ensure the integrity of the keyword analysis.

Joint Capability Area Level 1	Keyword
C2	Command and Control; C2
Netcentric	NetCentric; Network & Centric
BSA	Battlespace & Awareness; Intelligence & Surveillance; ISR
Building Partnerships	Coalition; All(y)(ies)(ied)

Table 1 Keywords used for JCA Level 1 survey

Joint Capability Area Level 2	Keyword
C2 – Organize	Organize
C2 – Understand	Situational Awareness
C2 – Planning	(Planning & Strategy); Course of Action; COA
C2 – Decide	Decision & Support
C2 – Direct	Direct & Communicate
C2 – Monitor	Monitor & Effects
Netcentric Information Transport	(Wireless & Transmission); (Wired & Transmission); (Switching & Routing)
Netcentric Enterprise Services	Enterprise
Netcentric Net Management	(Network & Management); (Spectrum & Management); (Cyber & Management)
Netcentric Information Assurance	(Information & Assurance); (Security & Protect)
Building Partnerships - Communicate	(Domestic & Foreign); Partnership & Adversary; Partnership & Competitor
Building Partnerships - Shape	(Partner & Foreign) AND (Government OR Institution)
Battlespace Awareness - ISR	(ISR OR (Surveillance & Reconnaissance)) & (Planning OR Collection OR Processing OR Exploitation OR Analysis)
Battlespace Awareness - Environment	Environment & (Collect OR Analyze OR Predict OR Exploit)

Table 2 Keywords used for JCA Level 2 survey

C2-Technology Area	Keyword
Decision Support	Decision Aid, Target tracking, Threat analysis, Threat response, Decision modeling, Option modeling, Semantic analysis, Workflow modeling, Decision modeling, Decision support, Data fusion
Planning	Meteorological data, Course of action (COA), Plan monitoring, Re-planning, Path planning, Asset allocation, Semantic Inference, Wargam(e)(ing), Mission plan,
System Architecture	Enterprise service bus, Service oriented architecture (SOA), Service discovery, Cloud computing, Semiotic, Access control, Operator interface, Manpower reduction, Peer-to-peer, Knowledge management, Network impacts, Data linkage, System of systems, Human computer interface (HCI), Solider machine inter(face)(action), Solider centered
Network Architecture	Scalability, Ad hoc net, MANET, Cybersecurity, Sat(ellite)Com(munication), Quality of service (QOS), Network topology, Network protocol, Tagging and tracking, Network management, Network discovery, Network simulation, Waveform, Datalink, Software Defined Radio, Wideband, Narrowband, Antijam, IA architecture, Wireless net
Organization Architecture	Database support, Social analysis, Social network, Info(rmation) management, Autonomy, Chain of command, Edge organization
Collaboration	Key leader engagement, Policy assessment, Social network, Dynamic team, Virtual team, Computer mediated; All(y)(ies)(ied), Coalition, NATO, Non-governmental Organization(NGO), Joint op(s)(eration)
Information Sharing	Information sharing, Social network, Web-based sharing, Information distribution, Authoritative data, Chat, Instant Message
Situation Awareness	Situation(al) awareness, Common operati(ng)(onal) picture (COP), Information modeling, Visualization tools, Sensor fusion, Geospatial Information Systems, [Information & surveillance & reconnaissance], ISR, C4I, Persistent stare, Persistent surveillance, Sig(nals) int(elligence), Remote sensing, Head mounted display, Vision enhancement, Sensor data, Battlespace awareness
Inter-operability	Data standards; Model driven architecture, Ontology matching, Semantic interoperability, UCORE, JC3IEDM, Microformats
Intel Analysis	Content Extraction, Deception detection, All-source analysis, Geo-spatial Data management, Intelligence Tool, Multi-lingual, Intel(ligence) analysis, Imagery

Table 3 Keywords identified for each of the technical areas

JCA Level 1 Survey Results

We used our keyword search to identify the level of effort that supports each of the JCAs. We see a distribution of funding which is heavily focused on C2 and Battlespace Awareness (Figure 2). Interestingly, we note that in the full data set (budget activity levels 1-7), we found that programs related to the C2 JCA were more highly funded than the others by more than a factor of two, indicating the higher costs as these systems move through test and evaluation to fielding.

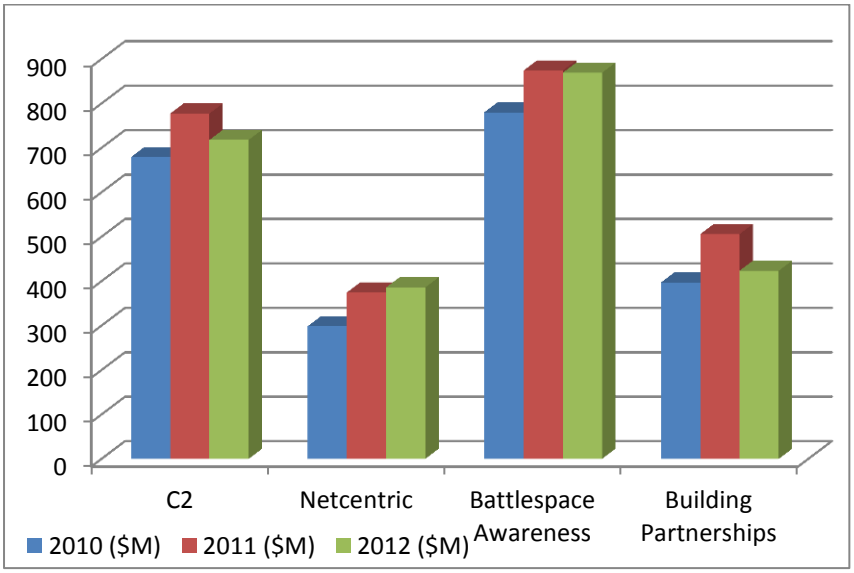

Figure 2 The financial breakdown of S&T (Budget Activities 1-3) programs interpretable as supporting each of the Level 1 Joint Capability Areas. Note that there can be overlap.

The Level 1 JCA analysis gives us clear insight that programs in the earlier stages of research and development are using the language as captured in the high level JCAs to describe the goals of their research in terms of military objectives. We take this to mean that these programs are intended by funders and program managers to support the high-level goals of the JCA. We compare this to our analysis below of the research actually being performed, to better identify the likelihood of these research programs addressing the final goal.

JCA Level 2 Survey Results

The JCA Level 1 search identified in a broad way which programs were explicitly in support of each of the four areas. For a finer level of resolution, we additionally identified the Level 2 JCAs using a similar survey technique. The survey was applied with keywords as described in Table 2 to determine the distribution of funding and numbers of programs for each of the level 2 JCAs.

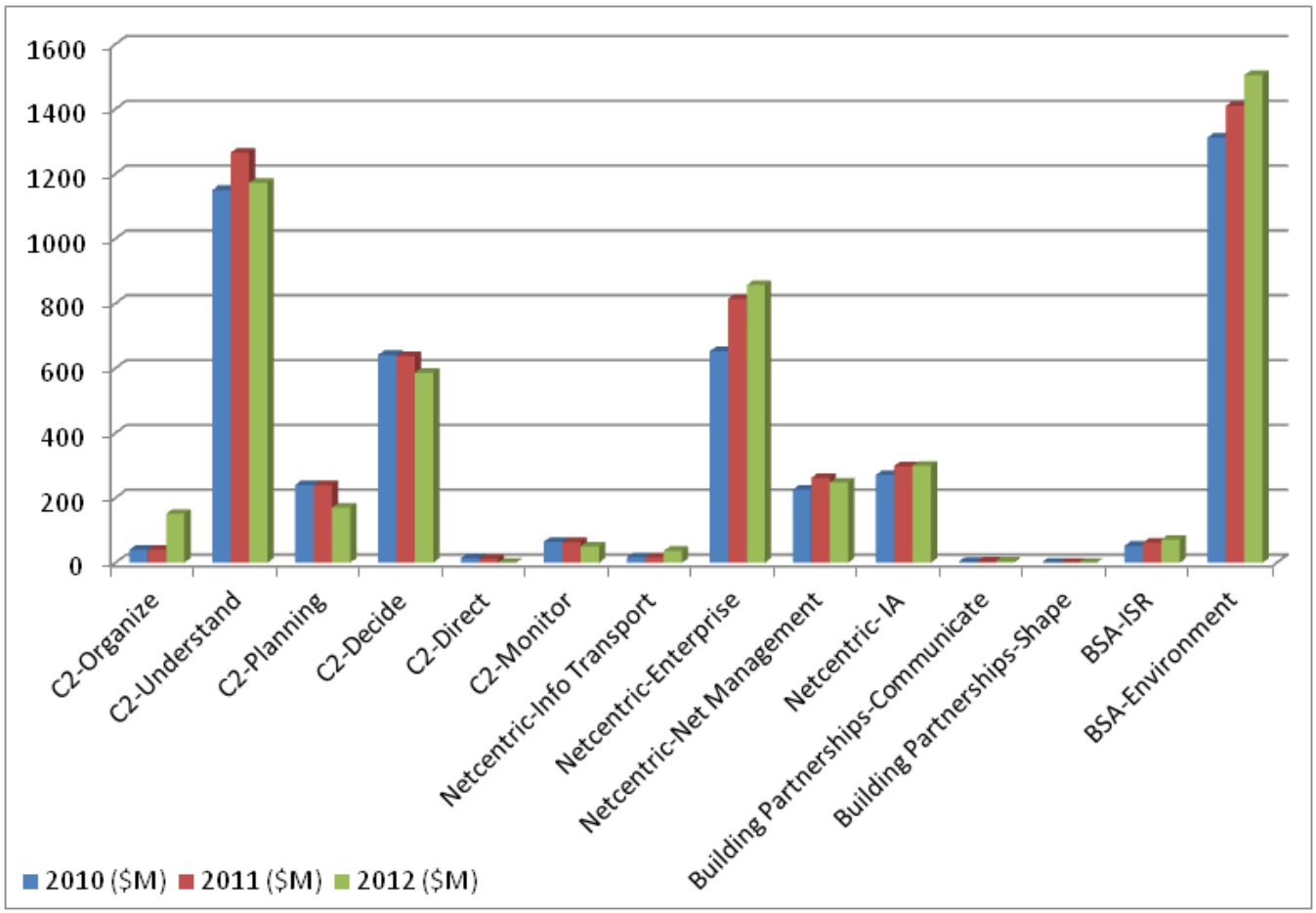

Figure 3 The financial breakdown of S&T (Budget Activities 1-3) programs interpretable as supporting each of the Level 2 Joint Capability Areas. Note that there can be overlap.

In Figure 3, we see that *BSA-Environment* and *C2-Understand* are the two most highly represented in the survey results, followed by *Netcentric Enterprise* and *C2-Decide*. From our experience in analyzing C2 research, we expect these categories to be highly represented. BSA-Environment includes sensing and intelligence gathering, C2-Understand is situation awareness and C2-Decide contains decision support systems; these topics logically being part of many C2 programs. Netcentric-Enterprise, on the other hand is a less traditional topic and reflects more of an emphasis on information technology trends towards service oriented architecture and enterprise-wide applications.

The ability to map the JCA description to the keyword varied in each of the categories. For example, *C2-Understand* maps directly to 'situational awareness' as a keyword. Additionally, due to the simplicity of this particular keyword mapping, we have more confidence in the ability of our technique to correctly identify the programs. In other cases, such as *C2-Monitor* ('monitor' & 'effects') for which we do not have a predisposition to expect prevalence, we also have less confidence that the programs identified in support of this goal are complete. The difficulty is due to an inability to map the

JCA to an exact or a common synonymous keyword; the exact language “monitor effects” is unlikely to be used, and searching for each keyword individually results in a large number of unrelated programs. Thus an exact interpretation of the results is not always possible across all the topics. However, we maintain that the use of the JCA-style language is an indicator of the *intent* of a particular program to meet the goal, and therefore still useful in comparing this analysis to the results of our third categorization scheme.

Technical Areas Survey Results

The results of the technical keyword analysis on the database are shown in Figure 4. We see a major focus in the technical areas on *situation awareness*. This is due to the fact that situation awareness serves as both a central goal of C2 as well as an important technical area, i.e., many technologies support situational awareness, and can be directly identified using that keyword. In addition, many sensor technologies are under programmatic development, and are also identified as a technical research area within situation awareness. *Network architecture,* on the other hand is also a dominant subject of research, and is not typically identified by name, but simply by the technologies under development (datalink, spectrum, etc.) These two subjects have in common, however, a status as the basic infrastructure upon which other C2 programs reside. In fact, the acts of obtaining the data and physically communicating it serve as a precursor for almost all the other technical areas (information sharing, collaboration, etc.). Therefore we believe the distribution identified here is appropriately reflective of actual warfighter needs.

The broad technical areas can be mapped to the JCA-based capability areas as shown in Table 4. The mappings are not one-to-one, but the most appropriate areas are connected. For example, the important and prevalent subjects of cyber-security and cyber-defense would be addressed in several different ways and therefore we expect them to be found under a number of technical areas. In this case, we believe that cyber-security maps to Organizational Architecture, Situational Awareness, Collaboration, System Architecture, and Network Architecture. On the other hand, C2-Planning and Netcentric-Information Transport are much less diverse in terms of technical solutions and therefore each maps directly to one technical area (Planning, and Network Architecture, respectively.)

Joint Capability Area Level 2	Broad Technical Area
C2 – Organize	Organizational Architecture, Decision Support, Collaboration
C2 - Understand	Decision Support, Intel Analysis
C2 – Planning	Planning
C2 – Decide	Decision Support
C2 – Direct	Organizational Architecture, Information Sharing
C2 – Monitor	System Architecture,
Netcentric Information Transport	Network Architecture
Netcentric Enterprise Services	System Architecture
Netcentric Net Management	Network Architecture
Netcentric Information Assurance	System Architecture, Network Architecture
Building Partnerships - Communicate	Information Sharing, Collaboration, Interoperability
Building Partnerships - Shape	Collaboration
Battlespace Awareness - ISR	Situation Awareness, Intel Analysis
Battlespace Awareness - Environment	Situation Awareness

Table 4 Mapping between Level 2 Joint Capability Areas and the Broad Technical Areas

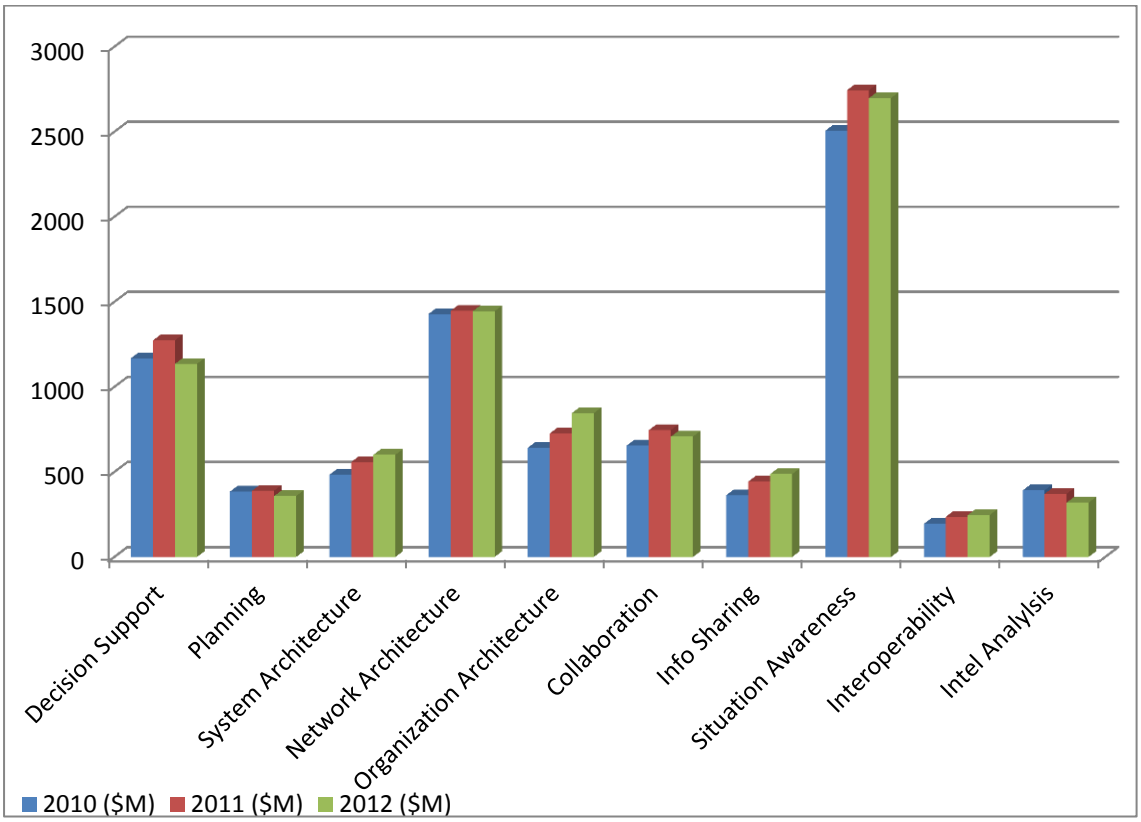

Figure 4 The financial breakdown of S&T (Budget Activities 1-3) programs interpreted as supporting each of the identified Technical Areas. Note that there can be overlap.

Comparison

By applying the mapping shown in Table 4 between the technical areas and the Level 2 JCAs, we are able to identify the efforts by technical area, and sum the funding based on which JCA the technical area supports (Figure 5). Using this method, we see a much more even distribution of funding over all areas than in either of the previous schemes. We see that some areas which were not well represented in our initial analysis (e.g., *C2-Direct*) are actually being funded at a higher level than expected from our initial analysis. We believe this analysis is more accurate than the previous categorization and reveals a healthy, generally even distribution of funding across the Joint Capability Areas, without major gaps in coverage.

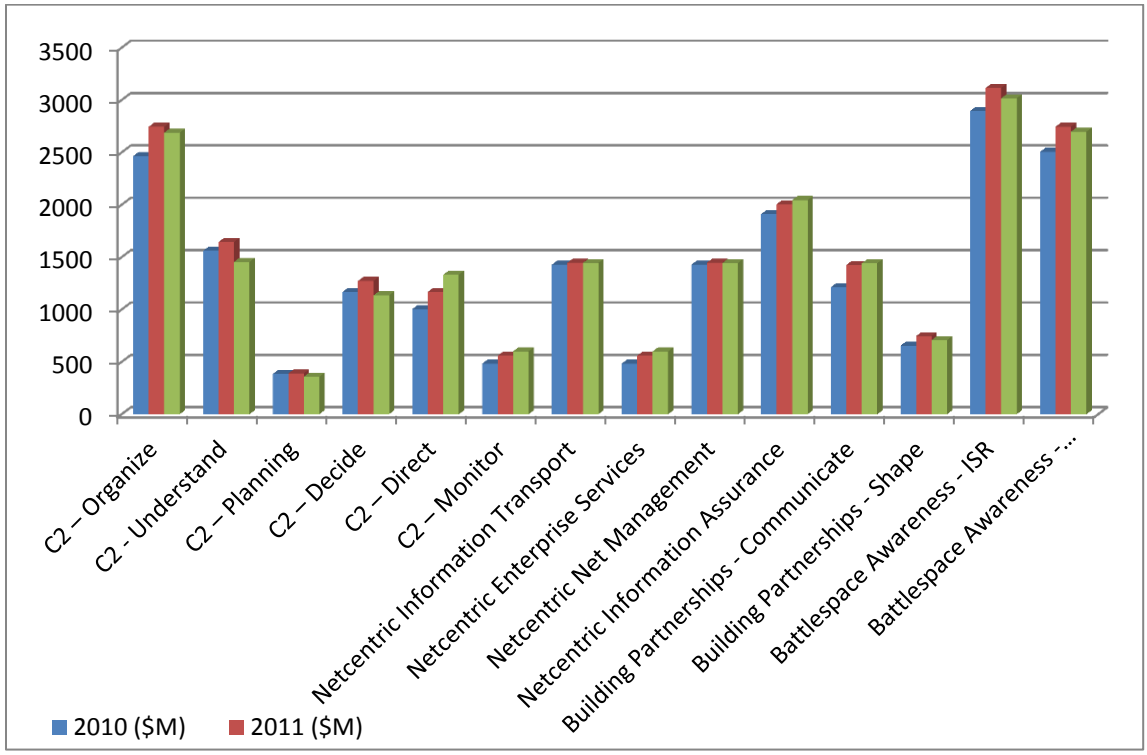

Figure 5 Interpreted Funding levels for JCA Level 2, as identified by technical area. Note that there can be overlap.

Trends in Command and Control

We additionally surveyed the database for research supporting various trends that we have observed in military command and control. For instance, analysis of current military tactics indicates that a transition towards a decentralized command and control paradigm is taking place. Through literature surveys, attendance at conferences and on-going discussions with service-members, we have identified certain programs and organizations which contribute to this, as well as doctrinal support and an overall strategy of department wide transformation *[5]*. To identify the prevalence of research programs committed to furthering this process, we searched for terms related to decentralization. Results are shown in Figure 6.

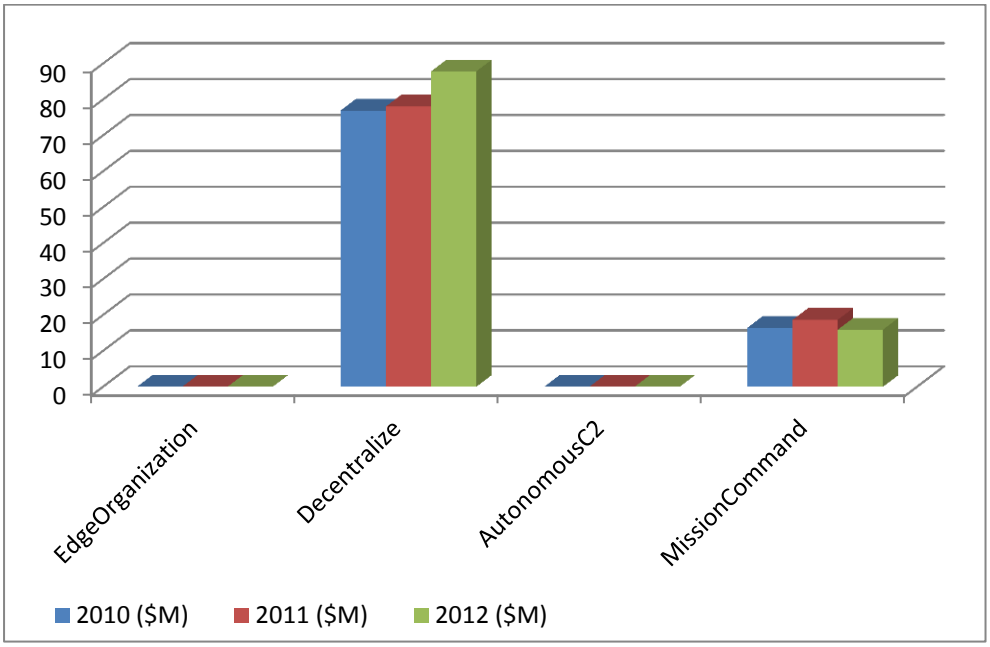

Figure 6 Trends: C2 Decentralization

We see that the explicit use of the terms indicating support of these decentralized C2 concepts is minimal, if it occurs at all. This lack of acknowledgement could have more than one interpretation. First, use of the terms may simply lag behind the development of technology in the program descriptions. Second, we have found that a cultural resistance to the transition exists at mid-levels in the US military [5]. Therefore, while technologies enabling decentralized C2 may be in the process of research and development, the full extent of their capabilities may not be utilized, due to inertia in the management architecture.

A second trend we have identified is towards using Commercial-Off-The-Shelf (COTS) Information and Communications Technologies (ICTs) [6] [7] [8] [9]. The extremely broad availability of cheap, advanced, commercial ICT has placed unprecedented powers of information creation, processing and distribution in the hands of almost anyone who wants them—friend and foe alike. The DoD has realized the need to embrace commercial technology and has initiated some responses [10]. In this case, we are specifically interested in information technologies developed by the private sector. We surveyed the programs for keywords indicating use of commercial technologies. The results are shown in Figure 7.

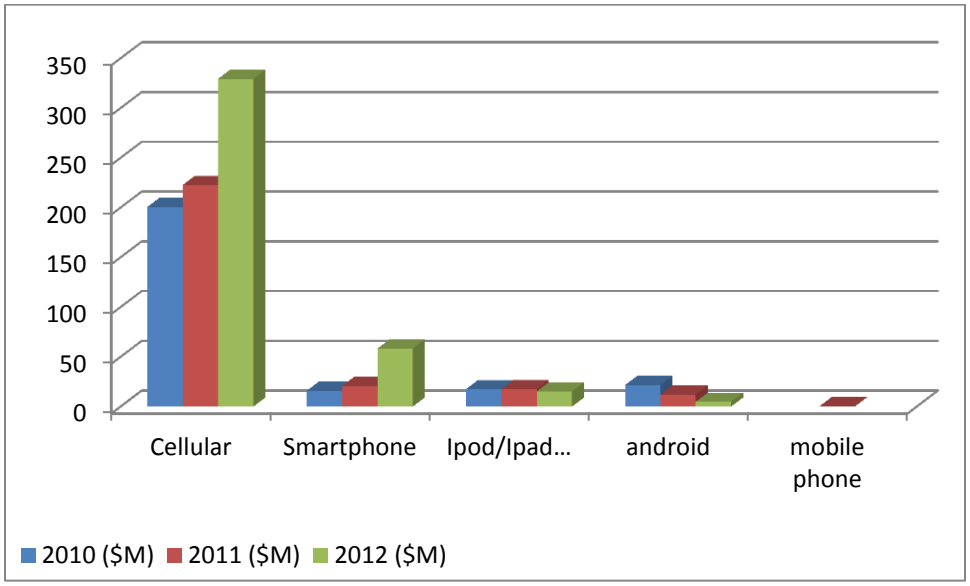

Figure 7 Trends: Commercial Technology

Here, we can see that cellular technologies are in development or adaptation. However, we were surprised to see that despite much verbiage devoted to incorporation of specific smartphone technologies in military applications, the technologies themselves are not described as being heavily explored by the documented research. There are several potential explanations for this result. Research may, in fact, be being performed into these technologies, with virtually no programmatic documentation. This would not be entirely surprising, as research documents are often written to describe high-level goals, and may be open-ended in terms of the most specific details. There are also a number of smaller scale pilot studies taking place which are not funded from specific programs in our database but from various other categories of funding, such as Operations and Maintenance. Based on our interactions with the services, it is our belief that these explanations are more likely than the more pessimistic interpretation (i.e., that there is a mismatch between the rhetoric being communicated by the services, and the actual efforts being made). While there may be bureaucratic and political hurdles to the incorporation of COTS technologies, we believe that there is a good faith effort in the service labs, etc. to explore this valuable option.

Conclusion

We can see from the foregoing data and analysis that there is a relatively high level of funding being applied to research related to Command, Control, Computing, Intelligence, Surveillance, and Reconnaissance (C4ISR). In fact, nearly 40% of FY 2010 R&D funding was applied to programs that can fairly be interpreted to support this broad area.

Much of this C4ISR-related funding is applied to developing *situation awareness* technologies, as well as development of the necessary *network architecture* for communications. These areas could be viewed as laying the foundation for the higher-level *information sharing* and *collaboration* areas.

One observation we can make is that the broad technical area of *organization architecture* is receiving relatively less (but certainly not zero) attention. This area is interesting because it encompasses a number of critical topics that are likely to be important for increasing C2 effectiveness in the future. An example is a fuller understanding of data and information quality [11] [12]from an enterprise perspective ([13]). Another is the development of fundamental knowledge on the effects of trust in sociotechnical networks—appropriate trust assessments can move the right information expeditiously to the right entities, whereas mistrust can freeze information in place ([13]). These are only a few of the possible examples falling into the broad category of Organization Architecture, and we do not mean to imply that they are being deliberately ignored. A full understanding of such specific topics that might require more attention would necessitate a more highly granular definition of technologies and a more detailed analysis than we have been able to perform thus far.

Another observation is that relatively few research programs make specific reference to two important trends influencing future command and control: one is the trend toward increased decentralization, and another is the increasing availability of advanced commercial information and communications technology. In the first case, much relevant research is being pursued, but simply not being verbally cast in terms of the trend. In the second, it seems likely that the relevant research is still in its infancy.

We see also that there is often a disparity between the language used in programmatic-style documents such as the *C2 Strategic Plan*, and the technical subjects under research. However, our analysis, mapping one to the other, shows a roughly even distribution of funding among the JCAs thus interpreted.

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Disclaimer

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