COMMANDING POSITION

GPS, TELEMATICS, AND THE DUAL-USE CONUNDRUM

Master of Arts in Law and Diplomacy Thesis

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ABSTRACT

The Global Positioning System (GPS) is the single most important element of the US' dominance of the art of conventional warfare, but it will also likely become, like the internet, a key platform for the telematics revolution: the commercial exploitation of geographical data sensors, databases, computing technology and communications for "spatially aware" applications. This paper examines how commercial competition between GPS and the EU's new Galileo satellite navigation system traces the lines along which military strategy, technology innovation, and "dual use" proliferation meet; and what guiding principles might help policy makers reconcile the interests of commerce to national security. It focuses particular attention on the blurring of the distinction between commercial technology and military technology, and the special part that network "ownership" and technological dominance play in managing the after effects of the proliferation of high tech conventional weapons.

The sustainable match between the benefits of telematics and the costs of dual use technology proliferation is dependent on the US striking a complex balance between preventing diffusion of some technologies, allowing the proliferation of others, while at the same time hedging risks to forces by standing up effective countermeasure protection. "Dominate the market" strategies to control proliferation imply control of the commanding heights of the information age -- the networks, and the sensing and computing power that rest on its fringes. The lesson drawn from the US-EU dispute over Galileo is that if the US is to build new geo-positioning network infrastructure, it should be willing to share in its development with others, lest it attract competition.

COMMANDING POSITION*: GPS, Telematics, and the Dual-Use Conundrum*

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INTRODUCTION

"a universe comes into being when a space is severed or taken apart...The act is itself already remembered, even if unconsciously, as our first attempt to distinguish different things in a world where, in the first place, the boundaries can be drawn anywhere we please.[1]

The 1991 Gulf War was the first war in which an armed force came closest to operating in a truly "networked" fashion, utilizing layer upon layer of communications links across the theatre and back to commanders in the US. Events of the war transpired across two separate, but parallel domains, with actions on the ground simultaneously being reproduced and broken down on computer screens and over command and control networks. The lines between strategic intelligence and tactical surveillance blurred, and so did the line between local and global communications and command. For centuries, armies were tied to their local geography and were required to keep tight formations to maintain lines of communications. A commander would "lay his 'axis of attack' along major roads or across open fields so troops could quickly penetrate into an enemy's rear once they broke through the front line."[2] Since military formations could often only fire in one direction, the alternative for a commander was to attempt to out-gun his opponent with long range artillery, or with much greater difficulty maneuver large forces to flank, which required a disciplined force that could orient itself precisely in reference to the target, as well as move quickly and quietly without detection. By the 1991 Gulf War, the use of global positioning receivers, radio communications and electronic links to intelligence assets such as satellite and airborne ground radar, a lowly tank commander could determine the location of enemy forces, as well as his own location, and move his battalion with confidence and speed to flank. Staying in tight formation became less important for maintaining communication, and so geography also became less important. Indeed, instead of geography defining military formations, the communication network began to shape the military organization and strategy.[3]

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[1] Spencer Brown, *Laws of Form*, (New York, Julian Press 1972) p. v
[2] Bruce Berkowitz, *The New Face of War: How War Will Be Fought in the 21st Century* (New York : Free Press, 2003), p. 74
[3] IBID, p. 74

Taken together, the concept of "network-centric" and "information" warfare did not simply accelerate traditional methods of war the way mechanization did. Rather, it upset the basic assumptions about how to plan and fight wars. The military has made great strides in establishing persistent intelligence, surveillance, and reconnaissance in the battlefield, integrating the full array of remote sensing and surveillance platforms to provide continuous target tracking and predictive battle space awareness over wide geographical areas. The US military's advantage over the rest of the world is its incredible ability to collect enormous amounts of data about the physical environment, paint an electronic picture of the battlefield, and distribute analysis to local commanders to enable them to attack opponents before they are able to stand up adequate defenses.

Much of the commercial promise of telematics is founded on the goal of creating the same kind of environmental awareness and predictability. Telematics is the blending of computers and wireless telecommunications technologies, ostensibly with the goal of efficiently conveying information over vast networks to improve a host of business functions or government-related public services. The most notable example of telematics may be the Internet itself, but the term has evolved to refer to transportation systems that combine global positioning satellite tracking, geographical information systems (GIS), satellite imagery, and wireless communications systems to create automated services that are environmentally "intelligent." For example, telematics innovation may create systems that can anticipate freeway congestion and automatically reroute traffic to less congested areas. In the air it may enable "free flight," allowing aircraft to control their own flight while optimizing overall traffic bandwidth, increasing airspace capacity, safety, and efficiency. Just as the network has made geographical dispersion more manageable on the battlefield, the network has made economic and geographical density easier to manage as well. The same kind of predictive awareness does not yet exist in geographical remote sensing applications, but there is significant potential that telematics may ameliorate a growing number of problems associated with economic growth and urbanization.

The Global Positioning System (GPS) is the single most important element of the US' dominance of the art of conventional warfare, but it will also likely become, like the internet, a key platform for the telematics revolution: the commercial exploitation of geographical data sensors, databases, computing technology and communications for “spatially aware” applications. This paper examines how commercial competition between GPS and the EU’s new *Galileo* satellite navigation system traces the lines along which military strategy, technology innovation, and “dual use” proliferation meet; and what guiding principles might help policy makers reconcile the interests of commerce to national security. It focuses particular attention on the blurring of the distinction between commercial technology and military technology, and the special part that network “ownership” and technological dominance play in managing the after effects of the proliferation of high tech conventional weapons.

TELEMATIC'S COMING OF AGE

The middle of the last millinea saw the advent of printing that allowed for the first time the widespread distribution of maps and opened, in conjunction with the discovery of celestial navigation and the invention of the compass, the age of exploration. Information technology now massively aids the provision of data for maps, first by managing the large amounts of data available as the result of advances in sensors and thereby the means by which they could be translated, and second by providing storage, processing, and data from large, spatially referenced databases. [4] Telematics innovation is the creation of novel interfaces between GIS, wireless terrestrial and satellite voice/data networks, satellite remote sensing and positioning. The technologies to determine location, extract relevant information and deliver it via a wireless connection are, however, only just starting to come together in the commercial world.[5] The creation of mass markets for computer technologies, and the evolution of interconnected networks made possible the information age. The development and deployment of sociogeographic data gathering, positioning, and imaging techniques are part of this greater reconfiguration of the use of information in society. [6]

Strategy: The Union of Space and Time

Harold Bruhns, an urban planner, sees telematics as a service package, a customer wrapping of three dimensional space in what is "an expandable invisible grid, constructed on a parallel plane on the substrate of telecommunications and computation."[7] Such a digital overlay seeks to accomplish what the military has been striving for centuries– complete integration of all intelligence into a single integrated, computed picture of the field, lifting commanders above Clauswitz's stubborn fog of war. Managing information for competitive advantage, taking

[4] Harry Bruhns, "Intelligence About Our Environment," in *Intelligent Environments: Spatial Aspects Of The Information Revolution*, ed. Peter Droeg, (Amsterdam ; New York : Elsevier, 1997) p. 261
[5] "The revenge of geography", *Economist,* Mar 13, 2003 p.55
[6] John Pickles, ed., *Ground Truth: The Social Implications of Geographic Information Systems*, (New York Gilford Press, 1995) p. vii
[7] Markos Novak, "Cognitive Cities: Intelligence Environment And Space," *Intelligent Environments: Spatial Aspects Of The Information Revolution*, ed. Peter Droege, (Amsterdam ; New York : Elsevier, 1997). p.386

advantage of asymmetries of information across actors in the marketplace is starting to take a strategic, and geographic dimension that runs closely parallel to the military example of what combat commanders collect in their search for their enemy's center of gravity, defined as "the characteristics, capabilities, or locations from which a military force derives its freedom of action, physical strength, or will to fight."[8] Strategy, in both the battlefield and the marketplace, becomes distinguishing friends from foes, and threats from opportunities over discrete time periods. For Michel de Cartau comes closest to what might describe a telematic strategem of dividing and describing space.

> Strategy is the calculation (or manipulation) of power relationships that become possible as soon as a subject with will and power (a business, an army, a city, a scientific institution) can be isolated. It postulates a place that can be delimited as its own and serves as the base from which relations with exteriority composed of targets and threats (customers or competitors, enemies, the country surrounding the city, objectives and objects of research, etc.) can be managed. As in management, every "strategic" rationalization seeks first of all to distinguish its "own" place, that is, the place of its own power and will, from an "environment." A Cartesian attitude if you wish, it is an effort to delimit one's own place in a world betwitched by the invisible power of the other...[9]

"Panoptic practice," that is, the division of reality into spatial units for the purpose of methodical observation, as geographer John Goss argues, is the exploitation of demographic GIS as a "visualization technology," one that posses the power to survey, capture and represent the economic resources objectively from an Archimedean position outside of social reality. Besides pan-optic practice, telematic strategy implies that systematic observations of dynamic environments be compared over time. The economic managers of dispersed human and material resources seek to track the impact of changes in their state, or alterations in their external environment over time, in order to reorient and optimize their use. But the concept is driven by market competition, and is akin to the military concept of the OODA cycle -- observation, orientation, decision, action cycle -- in which success depends on processing information in such a way as to get to the end of the decision process before your competitor can get to the end of

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[8] Department of Defense, Joint Pub 3-0, p III-20.

[9] Michel de Certeau *The Practice of Everyday Life*, translated:S. Rendell, (Los Angeles: University of California Press) p. 35-36

his.[10] Absolute speed is much less important than the ability to move from resources from one "state" of application to another in response to environmental events. As Bruce Berkowitz argues, military commanders and business resource managers must have "superior transients." Telematics, ironically, not only delineates the outlines of power relationships visually and temporally, but also acts to concentrate those same relationships geographically. Telematics is becoming more important as urban areas grow and take on entirely new economic dimensions. Saskia Sassen, an urban planner, argues that telecommunications has actually made proximity more important, not less; and the net effect will be to increase the dispersion of economic assets, while at the same time increasing the concentration of economic command and control.

> The fundamental dynamic that I posit is that the more globalized the economy becomes, the higher the agglomeration of central functions in global cities. The sharp increase in 1980's of the density of office buildings evident in the business districts of the city's is the spatial expression of this logic. The widely held notion that collaboration has become obsolete when advances in global telecommunications should allow for maximum dispersal is only partly correct. It is, I argue, precisely because of the territorial dispersal facilitated by telecommunications advances that agglomeration of centralizing activities expanded immensely. This is not a mere continuation of patterns of agglomeration but, what I would posit, a new logic for agglomeration.[11]

From the perspective of many who actively think about the implications of the information revolution, to say that information technology and communications will actually increase cities dominance of the economy seems a bit counterintuitive --advances in telecommunication should result in greater dispersion of economic power—not more concentration. An explanation for this seeming contradiction lies with that fact that a fundamental change is taking place in the mode of global production: the transition away from growth in manufacturing to growth in specialized services. Entire service industries, such as finance, take place in cyberspace, but most others, such as transportation and manufacturing, live sharply divided on in both physical and digital planes. The connection between cyberspace and real space, however, is not so closely coupled.

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[10] Bruce Berkowitz, *The New Face of War: How War Will Be Fought in the 21st Century* (New York : Free Press, 2003), p. 90

[11] Saskia Sassen, "The New Centrality: The Impact Of Telematics And Globalization," in *Intelligent Environments: Spatial Aspects Of The Information Revolution*, ed. Peter Droeg, (Amsterdam ; New York : Elsevier, 1997) p. 19

> "…much is to be accomplished in integrating geographical data into information systems… although it is often helpful to think of the internet as a parallel digital universe, or an omnipresent "cloud", its users live in the real world where limitations of geography still apply. And these limitations extend online. Finding information relevant to a particular place, or the location associated with a specific piece of information, is not always easy."[12]

Aside from remote management of economic assets, telematics also entails newer, perhaps more intrusive business channels to market. It is conventionally accepted that 85% of business information has geographic attributes and that the map has become a critical tool for the visualization of the marketing terrains.[13] In short, the exploitation of geographically rich data will most likely bring new market awareness to business.

Telematic advances will likely be driven by three trends: 1) the increasing intensity of services -- of which much of the efficiencies to be gained will be through expanded transportation traffic management; 2) decrease in the cost and size of GPS receivers and their integration into other product portable computing platforms; 3) expansion of wireless networks and concomitant expansion of bandwidth; 4) expanding interfaces between GIS and remote sensing technologies; and 5) the creation of GPS augmentations that allow high accuracy positioning to the sub-meter level. Early applications will likely focus on transportation and on business problems and issues related to the mobile workforce.[14] Miniaturization of GPS receivers will likely guarantee that GPS will become a key ancillary technology to computing: Motorola, for example, just recently announced creation of its *Instant GPS* chip -- a self-contained, assisted GPS receiver small enough to fit in a wristwatch.[15] Insertion of such technology into new generations of mobile phones, laptop computers and personal digital assistants will likely spur a number of experiments in location based services such as electronic "concierge" services that orient travelers to various points of interest. In summary, the number of sensors capturing geographical information will increase by several orders of magnitude.

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[12] "The revenge of geography," *Economist*, March 13, 2003 , p.55

[13] Jon Goss, "Marketing the New Marketing: The Strategic Discourse of Geodemographic Information Systems," in *Ground Truth: The Social Implications of Geographic Information Systems*, ed. John Pickles, (New York Gilford Press, 1995) p.144

[14] ,"The GeoWorld Industry Outlook 2003," *GeoWorld Magazine*, Vol. 15, no. 2 December 2002.

[15] Scottie Barnes; "Motorola's instant GPS" *Geospatial Solutions*; Duluth; November 2002

Commercial Rationale for Telematic Applications

The key question for Sassen is what telecommunications advances will be applied to geo-centric functions in the new service economy, and how will these advances fit both the urban and rural landscape. In fact, tremendous uncertainties still exist on the potential benefits of extracting, storing, and distributing data related to services that have a major geographical component. The most pressing demand for telematics appears to be in managing expanding traffic in rail, road, air and maritime transportation. Many policy makers have seen economic growth put tremendous strain on existing transportation networks and, in recent years, transport issues have risen sharply on the political agenda of most countries, especially in areas where population density is the highest. Slowly, many municipalities are learning that economic growth and traffic congestion cannot be reconciled by simply building new infrastructure, as car traffic expands to fill up new road capacity in urban areas. As urban planner Al Goodwin laments: “All available road construction policies only differ at the speed at which the problem gets worse.”[16] Many policy makers and urban planners see telematic applications as one possible solution, a set of technologies that hold some hope of de-linking economic growth and expanding traffic.[17]

As congestion increases, and drivers begin to rival each other in the consumption highway bandwidth, telematics looks to finally provide a mechanism to reverse a traffic “tragedy of the commons.”[18] Most likely it will do this by providing some semblance of pricing that is linked to relative scarcity of transportation bandwidth. In Britain, car traffic has grown by 80% over the last 20 years and the government predicts that between 2000 and 2010 congestion will grow by 28% on inter-urban roads and 15% within big cities.[19] As gridlock is becoming a way of life, Britain has experimented with pay-per drive, road-pricing schemes. However, quite aside from the

[16] Harry Bruhns, “Intelligence About Our Environment,” quoting Al Goodwin, in *Intelligent Environments: Spatial Aspects Of The Information Revolution*, ed. Peter Droeg, (Amsterdam ; New York : Elsevier, 1997) p. 202
[17] Stephen Potter, “Telematics And Transport Policy,” IBID, p.199.
[18] Garrett Hardin is professor emeritus of human ecology at the University of California at Santa Barbara, in examing the 1832 work of William Forster Lloyd, a political economist at Oxford University, coined the concept of “tragedy of the commons” by looking at the recurring devastation of common pastures as the privatized gain of a graze would often exceed his share of the commonized loss in the short run on free grazing lands. Such tragedy marks failure of distribution systems to manage consumption in nonexludable resources. From the *Concise Encyclopedia of Economics,* http://www.econlib.org/library/Enc/TragedyoftheCommons.html
[19] Andrew Clark, “Pay per drive,” *The Guardian*, June 14, 2002

environmental concept of sustainability… "traditional supply led transport policies are physically an economically unsupportable, but governments have considerable political difficulty in accepting that the "rationing" of car use is inevitable." [20] Under political pressure, early telematic applications might instead try to put more cars on existing roads in a more efficient manner, essentially looking to increase existing transportation bandwidth. Such ideas such as "convoy" systems that essentially automate and centralize traffic management by inserting cars into optimized "processions" have been suggested, although such ideas appear to be an overly complex technical solution to a problem that might be easier solved through road-pricing. Pricing systems in other areas have appeared as well, but have yet to take off as service concepts and issues of privacy, equipment standards and interoperability evolve. Risk management has also been touted as a possible new frontier. Progressive insurance prototyped its new "AutoGraph" service, in which customers volunteer to have a telematic pack (a GPS receiver and wireless data modem) installed in their car, which not only measures how much a customer drives, but how safely or recklessly, and in what low or high risk areas.[21] Progressive's drive-by-mile-insurance trial floundered, however. The service ironically was felled by perverse form of adverse selection, as *AutoGraph* attracted only the best drivers – i.e. those demanding the lowest premiums -- which could not be reconciled with the high per-unit cost of the telematic pack. As car manufacturers begin installing these kinds of packs standard, such as GM's *OnStar* system, and data management policies and customer offerings are focused to provide users privacy (or at least compensate them for the loss thereof), a whole new portfolio of telematic services like Progressive's will likely become more attractive in the marketplace.

Improvements in the "precision" of GPS positioning, along with expanded integration with other systems, will make possible an expanded range of applications beyond timing/synchronization and traffic management. Sub-meter applications, those using ground based augmentations that correct for normal positioning errors, will enable precision machine control. Sub meter applications will allow exact navigation of snow plows on roads, tractors in

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[20] Jeff Rayport, "Windows into the soul: surveillance society and major high-technology." in *Intelligent Environments*, p.202
[21] "HBS Case: Innovation at Progressive (A): Pay-As-You-Go Insurance" Frances X. Frei; Hanna Rodriguez-Farrar "Progressive" Case no. 9-602-175., Apr 9, 2003. AND Progressive press release, *Usage-Based Auto Insurance Rating* System, Mayfield Village, OH, Jul 13, 2000 http://www.progressive.com/newsroom/2nd_patent.asp

fields or mining equipment in open pits, and these applications will evolve naturally along side sea/road/rail traffic management systems. Precision navigation will also help manage air traffic, which promises to increase by a third over the next ten years. "Free flight" navigation systems that broadcast the location, speed and heading of all aircraft in a given airspace will allow individual aircraft to fly closer together safely, as well as fly more direct routes, saving time and fuel in the process.[22]

The breakdown of GNSS services by market segment, documented below, estimates the relatively short run windfalls in transportation, fleet management, precision machine control, and timing and synchronization applications.[23]

Table 1: Global Navigation and Timing Applications for the US and EU

Application	***US Market by 2003 (millions)***[24]	***European Market by 2005 (millions)***[25]
Tracking, machine control (e.g. precision farming)	*$3,000*	*€65*
Maritime navigation	*$210*	*€6*
Mapping Sub centimeter accuracy (Rural electrification, telecom placement pipelines, oil gas and mineral exploration, Geological monitoring	*$3,120*	*€86*
Car Navigation, Fleet Management, Rail	*N/A*	*€2,034*
Mobile Communications	*N/A*	*€6,000*
Timing Synchrony for telecom and financial transactions	*$40-$100*	*€10*
Aviation airspace management	*$7100*	*€65*
Equipment	*$690*	*N/A*

[22] Erick Schonfeld, "The Dream of Free Flight," *Business 2.0*, Feb 23, 2001
[23] Other Applications of GPS are listed in Appendix 1
[24] US Department of Commerce figures- presentation November 2000. http://www.doc.gov (accessed 7/02)

As GPS receivers and onboard vehicle computers become standard equipment, telematics will likely usher the creation of traffic markets that are more and more influenced by real-time demand and supply of transportation resources. If the history of GPS is any indication, most future applications for telematics will be difficult to predict and will likely reach beyond familiar applications in transportation, especially given the proliferation of GPS receivers and the relative anonymity of the user base. For example, the Air Force, after shutting down a portion of the GPS constellation for maintenance, was surprised to hear commercial banks and telecommunications firms were scrambling to bring back up their management information systems that were also brought down as a result. As each GPS satellite contains a hyper accurate clock that transmit time to each other and to ground receivers, banks and telecoms began to use the GPS signal to synchronize their financial and network management systems' clocks found on major nodes dispersed around the globe. For a long time, there was not much understanding at the Pentagon as to the extent that commercial systems depended on GPS. Now, such timing services are taken for granted, and have become indispensable to national electronic payment systems and telecommunications networks. Other applications will likely surprise the Pentagon in the future, and expansion of commercial users will put more pressure on the Air Force to be a good "commercial" steward of the system.

GPS as the Keystone of Telematics

The value added to any network is found at its trailing edges, not the wires and routers but the applications that are plugged into it and shared across a user community. In the same way, GPS is a network, all be it one that is more akin to a TV station transmitting programming than one akin to internet that actually allows end users to both receive and transmit. In telematics, GPS is just one piece of a larger puzzle, for it requires concurrent innovations in the fields of geographical information processing and wireless communication.

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[25] Commission of the European Communities (1999), Galileo: Global Satellite Navigation Services for Europe. Meeting of the Council of EU Ministers of Transport, June 17, Luxembourg.

In general, most information technologies themselves are becoming more integrated, and thus more dependent upon each other. David J. Teece, in an article entitled *Profiting from Technological Innovation: Implications for Integration, Collaboration and Public Policy*, argued that strategic control of “co-specialized” assets can make significant difference in whether a firm can ultimately harvest profits from a technological innovation. Most specialized production assets themselves exhibit dependences upon one another, either bi-directionally (co-specialized) or uni-directionally (unilateral). Co-specialized assets are those for which there is a bilateral dependence, i.e. the absence of one negates the utility of the other. For example, the shipping innovation of containerization requires the deployment of co-specialized assets in ocean shipping and terminals, such as specialized cranes, and rail and truckbeds. Telematic applications themselves are a bundle of technologies that, when considering their objective (which is to communicate location) are co-specialized to each other. Although the lack of a GPS receiver in your car does not negate the usefulness of the mobile phone, and vice versa, when considering the problem being solved by telematics, the technologies are mutually dependent. What makes them co-specialized are the interfaces that are constructed, and the technology layers that process location information into useful analysis for other systems.

GPS has the worthy distinction of being the co-specialized asset *par excellance* of telematic commerce. No less important, it is the key to the US’ so called “revolution in military affairs.” GPS is a de-facto global utility, and it is today the only effective, globally accessible, space-based positioning, velocity, and timing platform. Given its importance, it is essential to examine how competition in Global Navigation Satellite Systems (GNSS) is unfolding on the global economic and political stage, and how the paths of commerce and geopolitics cross.

Competition in Infrastructure: Global Navigation Satellite Systems

The military importance of GPS for the US cannot be taken lightly. Of all of the NATO members, only the US could effectively conduct air operations in Serbia and Kosovo, and precision bombing was critical forcing Milosovic to buckle. Even more recently, GPS, along with spaced based imaging, was critical to success in Afghanistan and Iraq. Undersecretary of the Air

Force Peter B. Teets, describing the use of GPS to guide bombs to targets against the Taliban and al-Qaida in Afghanistan, stated frankly that GPS was “the single biggest contribution to the war.”[26] Most importantly, precision strike has in some sense ended war as an exercise in attrition, which has enormous geopolitical implications. US ability, through surgical strike, to inflict significant injury on opponents without wreaking a large number of non-combatant casualties has without a doubt made force a more politically acceptable option than it had been twenty years ago.[27]

The US is the only country that has been able to effectively integrate GPS into its military systems, and it has been weary to do anything that would risk its dominance in the area. A Rand study summarizes the US interest in maintaining its monopoly of GNSS.

> For several reasons, it is in the US interest to see GPS become widely accepted and employed around the world. First, the globalization of GPS markets provides an economic stimulus to firms in the growing US GPS industry, many of which already rely on exports for a significant share of their revenues. Second, technological preeminence is an important pillar of national power. The acceptance of GPS as the world standard for position, velocity, and timing applications enhances the position of the US and allows it to lead in one important part of the process of technological and economic globalization. Third, US national security is well served by the international acceptance of GPS […] The international acceptance of GPS would also slow the development of alternative satellite radio-navigation systems, the adverse use of which could be more difficult for the US military to control or counter in wartime.[28]

In the early 1990’s, GPS appeared to remain the unrivaled GNSS. In the early 1990’s the Russian GLONASS system appeared to be operationally sinking as financial support for the system waned. . At the same time, Europe and Japan were particularly interested in building GPS applications for managing their growing traffic problems. Japan, in cooperation with the US built a wide-area augmentation system, the Japan Multi-Function Transport augmentation (MTSAT) for air traffic. Europe began its own ground-based augmentation of GPS, dubbed EGNOS (European

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[26] Glen Gibbons, “No Good Deed Goes Unpunished” *GPS world* June 13, 2002, http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=21891, sourced June 26, 2002
[27] Elliot Cohen, “A Revolution in Military Affairs,” *Foreign Affairs*, March/April 1996. p.38
[28] 19NAPA/NRC, National Academy of Public Administration/National Research Council (1995), The Global Positioning System: Charting the Future, Report for the US Congress and Department of Defense, pp.14-15 (Washington, DC: National Academy Press).

Geostationary Overlay System). The initial purpose of EGNOS was to provide the EU experience to launch more sophisticated traffic management systems as a part of a wider initiative to integrate and rationalize trans-European communications and transport infrastructures and to promote deeper economic integration. In the 1990's, the US had the most operationally capable system, the largest user base, a vast portion of which was civilian, and it appeared to be locking in the evolving commercial standards for space based radionavigation.

In mid 1990's, the U.S. initially pursued cooperation with the EU directorate of Transportation on the European use of GPS for ground based augmentations and applications. As the EU began to debate openly the advantages and costs of building its own "space-based" system late 1998, U.S. outlined basic principles for further cooperation, stating that it would be willing to cooperate with the EU on the new system (i.e. on compatibility issues, time standards and reference coordinate systems) if the EU would agree to operationally subordinate its GNSS constellation to GPS.[29] When the EU decided to begin the concept definition phase of an autonomous, interoperable second generation GNSS that could leverage the large GPS user base, the US offer was withdrawn and negotiations ended.

Room at the Top: Galileo

The US argued that that there was "no need" for a separate GNSS, and that a modernized GPS service would be sufficient to meet user needs worldwide. In the past, since European aspirations in dual use space technologies seemed relatively easy to dislodge, such contentious tactics appeared to be the obvious strategy. But given the cool climate in relations, rough methods resulted in more European resistance, instead of more yielding as the US strategy assumed. Overly zealous lobbying designed to demonstrate to the EU the futility of moving forward with Galileo, had in fact alienated some EU members, such as Britain and Germany, which would have otherwise held out on Galileo, pursuing an option more in harmony with NATO. To build support for an independent system, the EU pointed to past US behavior to convince its European constituents that the US would be an unreliable and less than disinterested steward of

[29] GPS and Galileo: Commercial Issues at Stake, Department of Commerce – Office of Technology Administration Briefing http://www.ta.doc.gov/space/library/speeches/2002-04-24-ISAC-briefing.ppt , accessed 4/29/03

European investments in GPS if Europe were to forego Galileo. Given the ailing relationship between the US and Europe, the EU was probably easily able to cast serious doubt inside Europe on the sincerity of US commitments to keep GPS an open system, impartial to various competing national economic interests, and available to all commercial users with no stipulations or exclusions. After the Cold War, Joseph Nye and William Owens persuasively argued in *Foreign Affairs* that the US should replace the Cold War era nuclear umbrella over Europe, with an "information umbrella," based on US's potent intelligence collection and precision warfighting capabilities.[30] Their arguments in some sense predicted the origins of Galileo, where US refusal to share intelligence capacity would likely encourage others to match it.

The relationship between the US and European NATO members has in a sense become more fluid, since Europe is less dependent on the US for its security. US emphasis on burden sharing inside NATO has reinforced this trend. Despite the shifting burdens and responsibilities, however, the US has still sought to hold onto its prerogatives inside NATO, and to act alone without much restraint. The Kosovo intervention was a case in point: "….The complexities of diplomacy and, particularly, multilateral diplomacy are seen [by the US] as inevitable but secondary at best, needlessly burdensome and constraining at worst…The military plans for 'Operation Allied Force' in Kosovo came from the Pentagon and were not the result of multilateral consultation. Only validation after the fact occurred."[31] The lack of consultation on a matter in Europe's own backyard had angered some NATO members while making other's apathetic.[32] The US criticized the Europeans for failing to contribute sufficiently to its military operations (outside of peacekeeping) and the Europeans fault the US for failing to include Europe key decisions in Iraq and Afghanistan. These frictions have soured relations between Europe and the US, and such strains have tarnished the US's image.

An illustrative case in point: the French argued incessantly that the US often passed "low-grade or misleading intelligence" to Europe, mostly in an effort to bolster its version of events in light of US policy objectives. Germany, a far more cooperative and sympathetic ally of America's,

[30] Joseph Nye and William Owens, "America's Information Edge," *Foreign Affairs*, March/April 1996 p.22
[31] Francois Heisbourg, "American Hegemony? Perceptions of the US Abroad," *Survival*, Winter 1999-2000. p 7
[32] Francois Heisbourg, "European Defence, Making it Work," Chaaillot Paper #42, Institute for Security Studies, Western European Union, September 2000. p. 65 p 100

encountered what was probably inappropriate levels of obstinacy. In one incident, the German Ministry of Defense claimed that on three occasions, the US provided misleading or inadequate satellite imaging, and in doing so endangered German units then on critical mission in Kosovo. The US had attempted to scuttle German French cooperation on developing the HELIOS and KRONUS remote sensing satellite systems by attempting to strike a bargain with Germany over the purchase of a radar satellite from Lockheed.[33] In the past, since European aspirations in dual use space technologies seemed relatively easy to dislodge, such contentious tactics appeared the obvious strategy. Such divide-and-conquer tactics had convinced many in the EU and NATO, even those skeptical of the economic benefits of an independent GNSS, to support Galileo.

The logic behind the US strategy was to prevent the proliferation of military enabled GNSS applications. For the EU, the interest in an independent GNSS is to become less dependent on the US technologically, and to deny the US undo leverage in subsequent dealings on political and economic issues related to satellite positioning. Not only are the political implications of being dependent on the US for spaced based navigation services compelling, the stakes are also higher on the commercial side for the EU. For Europe, Galileo was considered critical in keeping Europe competitive globally, especially in telematics, where it already has a significant comparative advantage in such complementary assets as high speed mobile telephony/communications networks and equipment. Given that Europe has some of the highest traffic densities in the world, the EU estimated that Galileo would lead to €200 billion in indirect savings for each one percent reduction in travel time in road transport alone.[34] Just the direct short-term benefits, in the EU view, make Galileo worthwhile. EU Commissioner Palacio claimed that Galileo would create 140,000 jobs and a potential market of €9 billion a year. [35] The fact that Europe probably represents the biggest single market for GNSS applications for transportation management, and the EU wanted rather to see European firms capture the lion share of the system development and implementation business.

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[33] IBID. p.100
[34] Johan Lembke, "The politics of Galileo," European Policy Paper no. 7, University of Pittsburgh, University Center for International Studies, European Union Center, Center for West European Studies, [2001] p.9
[35] Technomar GmbH (2000), Structural Analysis of the European Satellite Navigation Applications Segment, Report commissioned by DG TREN/Commission of the European Communities, July, Brussels.

Nothing, however, prevents Europe from using GPS to achieve these goals. The EU considers the commercial stakes as "winner-take-all." Europe worries that whoever establishes early technological standard in telematic applications will likely dominate the world market, as telematic application vendors will likely pile on to whatever GNSS offers the best precision, best quality of service guarantees, and most appropriate interfaces --along with the largest pool of customer end-users. The main rationale for Galileo was its economic flexibility: the ability EU to optimize GNSS for commercial use. Ownership and control of their own GNSS network is touted as important for the EU, because it allowed them to accommodate of specific commercial requirements that are especially applicable to Europe. This is particularly in areas where GPS may potentially come short or in future areas where EU holds no hope of influencing development of GPS capabilities.

The EU argued that Galileo would differentiate itself from GPS by offering "guarantees for service" for civilian applications that require very high and consistent levels of accuracy. By guaranteeing service (with the EU possibly assuming legal liability for failures), Galileo hopes to attract many companies that would otherwise not be comfortable building critical "safety of life" applications, such as automated air navigation, to a system that it could not control, or at the very least influence. Since GPS is currently a free service, the US has consistently refused to accept liability for GPS accuracy and service levels, leaving it up to third parties to correct discrepancies through local ground based augmentations. The GPS "as is--with no guarantees" policy has been the major commercial argument for Europe to build its own system. Elements of competition between the still emergent Galileo and GPS have been seen recently. The Air Force, for example, recently included requirements for independent "integrity checking" in GPS III, set for launch at the end of the decade.[36]

[36] Sharon Weinberger, "DOT to begin new GPS III civilian requirements studies," *Aerospace Daily*; Aug 26, 2002

Co-specialized Assets and the Commercial Logic of Competition

Many in the EU, however, believe Europe could be locked out of important future markets, and that research, development and exploitation of telematics requires EU control of its own GNSS infrastructure. Control of over GNSS will likely be critical if R&D monies are to pay off. For example, telematic applications also require concurrent development and rollout of wireless telecommunications, GIS and GNSS ground based augmentations and infrastructure. Accordingly, capturing the benefits for European R&D make control of the GNSS infrastructure critical, especially when viewed from the perspective of the EU member states. Following Teece's logic, making large investments in ground based services that depend on another's network presents an element of risk that might not be entirely manageable.

> Generalized equipment and skills, almost by definition, are always available in an industry, and even if they are not, they do not involve significant irreversibilities. Co-specialized assets, on the other hand, involve significant irreversibilities and cannot be so easily accessed by contract, as the risks are significant for the party making the dedicated investment. The existence of assets that are co-specialized to the design are often the most difficult to obtain, and the most visible part of the manufacturing process.[37]

The "appropriability" of technology-- the capability to harvest exclusively profits from your technological discoveries-- depends on "co-specialized assets," especially in areas where intellectual property protection and trade barriers are weak, and where technologies can be easily copied or reversed engineered by imitators.[38] But with GNSS outside of Europe's "repertoire" of capabilities and assets, Europe industrial leaders and government officials fear that it will likely not be able to take advantage of its lead in mobile telephony to capture the externalities implied by telematics.[39] The competitive standpoint, the EU worries that exclusive US control of GPS will

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[37] David J. Teece,"Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy." *The Competitive Challenge*, ed. D. Teece, June 1986 p. 303

[38] IBID p. 295

[39] IBID, p. 303,

enable American industries to control the evolution of GPS in such a way as to advantage their technology in the marketplace.

At an immediate commercial level, Galileo would provide equity with the United States in global competition for emerging location-based service, but in the long run, some European countries argued, that not having control over a critical positioning and timing infrastructure would in the future undermine European sovereignty, security, and autonomy. Given the debate between EU members states on Galileo, the rationale for the system was just as much political as it was economic. Up until the end of 2002, there appeared little appetite among some EU members to spend public money on a project with no definitive benefit above and beyond what they were getting from GPS. US rhetoric sharpened, and US officials argued publicly that a separate GNSS would simply duplicate what Europe was already getting for free, that there was no business case for it, and that it would divert monies and bureaucratic energies that would be better spent elsewhere. The arguments, for a time, seemed to be working. In the definition phase, from 1999 to 2001, the EU continually delayed decisions to financially support Galileo, primary concerned about unanswered questions on the long run economic returns, security, and the legal structure for managing the system.[40]

Rumors in the press, and indications from some EU officials were that US pressure had killed the project.[41] Furthermore, perceptions were that the EU and the European Space Agency (ESA), working together on a major project for the first time, could not manage such an ambitious project, especially given the cost and time constraints. The US was well aware of this, and had much hoped that Galileo would slip and fall politically, especially if given a little shove by American lobbying. It is not entirely certain whether the major EU member states decided to make good on Galileo in June of 2002 despite US pressure, or rather because of it, though it is most likely a combination of the two. The challenge for Galileo now is to compete and win against GPS for the hearts and minds of application developers, and much of this depends on which

[40] Johan Lembke, "The politics of Galileo," European Policy Paper no. 7, University of Pittsburgh, University Center for International Studies, European Union Center, Center for West European Studies, [2001]   p.9
[41] "Europe GPS Plan in doldrums?" *GIS Development Magazine*, January 2002. http://www.gisdevelopment.net/magazine/gisdev/2002/jan/234col.shtml

system will be able to deliver on the promise of built-in integrity checking or "guarantee of service."

The EU needs a fully operational Galileo constellation up before 2008 if it hopes to better the Pentagon, putting its system in competition with GPS IIF, a stop gap primarily designed to replace the current aging fleet of satellites, most of which are at or near the end of their operational life. Huge investments will likely be required just to keep the system operating, let alone to modernize it.

> The health of the Global Positioning System satellite constellation is rapidly eroding, and the Defense Dept. is increasingly concerned that it won't be able to fix the problem on its own. More than half the GPS satellites in orbit are no longer fully operational, said Owen Wormser, the Pentagon's principal deputy for spectrum, space, sensors and command, control and communications. In addition, the Pentagon has no way to accurately predict when more of the spacecraft will fail, or what components might break. Fixing the constellation presents an array of hurdles. Wormser noted there are enough satellites built or being assembled that could be launched to reconstitute the constellation, but there are not enough launchers available to place the spacecraft in orbit. Pentagon officials accept some responsibility for the dire situation because they have not focused on the emerging crisis. Only now is the issue attracting attention at senior levels of the Defense Dept.[42]

The entire ground segment will likely need to be replaced in the next 4-5 years as well, in order to ensure that the Pentagon can update satellite parameters such as timing more frequently. He noted that more money is being spent on the ground segment than on the satellites. The EU ultimately hopes to win converts to Galileo should the US fail to fix its system in the short term, and modernize it in the long term.

Reconciling the Military and Commercial Uses of GNSS

The fact that the Pentagon viewed the issue of Galileo through a defense lens, rather than a commercial one is telling. Although averting the loss of its monopoly was itself highly motivating, another factor determining the US position was the existence of heavy bureaucratic

[42] Sharon Weinberger , Aerospace Daily; Washington; Aug 26, 2002;

friction between the US and the EU. Daniel Druckman argues: "the negotiation conference is the primary forum for defining and redefining and relationships among nations, whether they are friends or enemies."[43] The EU commission and the US Department of Defense, however, have such different worldviews that such "redefinition" is extremely difficult, because both sides speak two totally different political languages. Whereas the US frames the issues in more military terms (the chief negotiator for the US is a Department of Defense Undersecretary), the EU sees it more as a commercial issue, (whose representation comes from the Transport Directorate General). Viewing negotiations with the US strictly through a "commercial" lens, the EU had likely far surpassed US negotiators limits on what was open for discussion.

> [The Galileo] quarrel epitomizes many of the institutional contrasts between the EU and the United States. On the European side, the issue has been handled by transport ministers and European Commission bureaucrats with no mandate for, or experience of, dealing with the life-or-death issues of geopolitics and war. The risk exists that the EU's permanent bureaucrats, who have a culture of sparring endlessly—but harmlessly, most of the time—with the Americans over commercial issues, could stumble into a transatlantic defence row they never quite expected. [44]

G. Winham argues that there is a fundamental difference in mindset and process orientation between commercial and security negotiators. His contention is that, whereas security negotiations are often motivated by a desire to "defend existing realities in international relations," commercial negotiations often originate from an directed effort "to create new realities in the international environment."[45] The EU Commission's de-emphasis of security, rationalized by the its declared intention to make Galileo a strictly commercial enterprise, compounded US perceptions of the EU naivety, and thus served as a big disincentive for the US to offer a compromise solution acceptable to all.

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[43] Daniel Druckman, "Stages And, Turning Points, And Crises. Negotiating Military Base Rights, Spain And The United States." *Journal of Conflict Resolution*, volume 30, #2, June 1986
[44] "Eppur si muove—or maybe not," *Economist,* May 30, 2002
[45] G. Winham, "Multilateral Economic Negotiation." *Negotiation Journal*, April 1987, pp. 175-189

Up to March 2002, the US withheld cooperation with the EU on any system that would not be subordinated to GPS and the NATO command structure. In the meantime, for two years the commercial case for Galileo moved forward inside the EU Commission, and the US responded by ending low-level technical discussions. The decision to withhold technical cooperation was a mistake. Without input and oversight from the US technical teams, engineers writing up Galileo spectrum definition documents had to make a number of decisions that, unbeknownst to the US, adversely challenged the GPS modernization project --perhaps purposely. Pentagon officials were shocked and angry to discover that the Galileo public signal would partially overlay, and therefore interfere with the encrypted GPS military code. Figure 2 maps out the allocation for GPS (in Yellow, *L5* , *L2* and *L1*) and Galileo (in Blue: *E5*, *E6* and *C1*), and illustrates the overlay in the *L5/E5* and *L1* frequency bands.[46]

Figure 1: Frequency allocation for GPS and Galileo (2000)

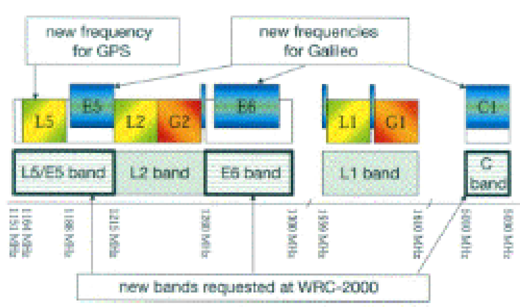

Figure 2 — Radionavigation-satellite frequencies requested at WRC-2000

The allocation had foiled the Pentagons program to clearly separate GPS spectrum from Galileo's. At that time, contingency plans were being formulated, calling on the US to jam Galileo in the event that it should be used against US by a third party during a military crisis. In the future, in exchange for cooperation on the overlay issue, the EU will likely demand from the US full GPS compatibility with Galileo, and even perhaps favorable commercial and regulatory treatment for emerging European telematic platforms that would enable them to take advantage of the larger

[46] ITU World Radio Communication Conference ,François Rancy, Director, Spectrum Planning and International Affairs, 2000 pg. 4 ---Part of the L5 band is allocated to US M-Code while a second part is allocated to the Galileo PRS signal. The M-Code and the PRS are the US and the EU's respective public/military encrypted signals for Government use only are so close to each other that they will likely overlap.

GPS user base. To date, no contingencies have been publicly discussed to limit GPS or Galileo availability in the event of an emergency. The overlay issue is still alive and will likely require the US to return to the negotiating table and to restart technical discussions on the reallocation of the GPS and Galileo frequency bands.

Cooperation on Managing Dual Use Infrastructure

Part of the US strategy to date has been to lock the rest of the world into the GPS infrastructure, enabling the US to prevent enemies from exploiting GPS to conduct their own "surgical" strike operations in wartime. Control over GPS enables the US to render the non-encrypted GPS civilian signal unusable during a crisis, either through manipulation or cessation of the signal during wartime. The existence of a viable GPS competitor, however, requires a totally new strategy, one that is much less certain to work without complete cooperation from all GNSS operators. The EU's March 2002 commitment to begin construction of the Galileo network, and China and Russia's partnership to revive the aging GLONASS system means that the US may need to develop two strategies forward. The first will be to obtain commitments, just ahead of crises, from Russia and the EU operators to make their signals unavailable in the event of specific contingencies. Agreement on limiting access to GNSS signals in wartime contingencies will be extremely difficult to forge; if not for political reasons, then because continuity of service issues will likely preclude it. This, after all, was part of the prevailing justification for Galileo. Unfortunately, shutting off or manipulating service will have consequences for commercial users that are not likely to be isolated to the designated contingency or theatre of war. Being able to turn the selectively limit user access to GNSS is a technical problem that engineers in the US, Europe and Russia are all probably seriously contemplating.

The second strategy will be formulating an operational plan to jam these systems locally in wartime. Yet countermeasure strategies are of limited use unless there is some semblance of stability and predictability in the technologies that an adversary chooses employ in weapon systems. Internal inertial navigation systems, optical range finders, and other sensors are all key components of precision strike weapon systems that have their own technological trajectories.

Since the greatest value-added to most new military weapons are the information systems inside them, the spread of sophisticated components, through the conduit of commercial markets for information technologies, represents a “moving target” for military planners. In a much different environment from the Cold War, the greatest advances in information technology are in large part coming from the commercial world, as mass markets for information technologies have made possible tremendous scales of production, producing learning economies that the military has supplemented with cutting edge research and development, but for the most part is not in a position to match.

To date, no potential military rival to the US has been able to master the art of modeling the physical world in cyberspace, but as telematic applications integrating satellite communications, imagery and geo-positioning evolve and find niches in the commercial world, the technical barriers will fall over time. The first half of this paper explored the international impact of GNSS competition from the top-down: from the perspective of the network infrastructure and the applications attached to it. The second half looks at the consequences of the diffusion of telematic technologies from the ground up -- that is, by looking at the spread of dual-use system “building blocks,” and the dynamics that drive their creation in the marketplace, and insertion into military applications.

THE "DUAL USE" CONUNDRUM AND TELEMATICS

The expression "dual use" technology began to receive special attention in the 1990's as the Cold War ended and the "internet age" began. "Dual use" became a Pentagon buzzword, but it did not mean the same thing to all people. It appeared in three different post cold war contexts within the defense community: acquisition reform and force transformation, defense industrial diversification, and weapons proliferation. Each of these contexts is informative in understanding how the spread of "dual use" systems such as GPS have been viewed ambivalently as both a tremendous opportunity and a serious, perhaps unmanageable threat. This chapter focuses on "dual use" as it applies to innovations in the first context: acquisition reform and force transformation, addressing elements of the second context, defense industrial diversification. The next chapter addresses the last context: the spread of commercial navigation technologies and the proliferation guided weapons.

Dual Use and Industrial Diversification

The Cold War dichotomy of defense versus commercial technology began to break down in the late 1980's. The "two sector model" implied that most technologies could be categorized as either civilian or military, with a only a rare few falling into the category of "dual use." For technical and cultural reasons, shifting manufacturing resources used for production for military markets to use for civilian markets was considered complicated and much more the exception than the rule. By the 1990's greatly reduced defense spending led to a huge round of mergers by defense industrial firms designed to improve their competitiveness in the much smaller market. These larger firms also diversified into non-defense lines of production as well, and began to integrate manufacturing across the civilian-military divide. Smaller defense budgets, the consolidation and diversification taking place in the defense industry, and the explosion of commercial demand for electronics and information technologies slowly ate away at the two sector model.

In the 1990's, defense manufacturing lines shifted to commercial production. A MIT study of 21 industries engaged in the machining-intensive goods (MDG) sector determined that 80% of the establishment with defense contracts integrated commercial and military production in the same facility. Of this sample, more than half were defense purchases of durable goods (including aircraft and ordinance), but the MDG sample did not include electronic or computer products, which usually are more often seen as one of the preeminent examples of dual use technologies. The authors concluded, "commercial-military integration is not only feasible but is largely the normal practice at the end of the cold war."[47] The MIT study was complemented by a separate study by the Program on Regional and Industrial Economics (PRIE) at Rutgers University, concluding that companies facing the prospects of fewer government contracts after the end of the cold war had lowered their defense dependence by mainly expanding civilian sales rather than by reducing defense sales.[48] Both of these studies can be criticized by their overemphasis on the experience of middle size firms, and neglect of the major prime contractors. However, from both it possible to conclude that a "mixing" of facilities supporting defense and civilian markets is occurring, and that there are likely learning economies in design and manufacturing process innovations taking place between the two, despite the cost wedge associated with the higher administrative burden of managing defense contracts.

The fact that military production lines could be easily reorganized to produce and commercial products (and vice versa) is telling. A small group of military planners and academics interested in the dynamics of technology development began to recognize that military technological innovation was not so isolated from the rest of the economy as was once assumed. This group saw defense technology as really a part of a much larger civilian technology base with, as X describes, "…shared roots in a common education system, shared interest in a range of generic technologies through companies that serve both military and civilian markets."[49] Those that saw the defense industrial base in isolation tend to view its end product as a slow and steady series of discrete technology platforms –tanks, bombers, ships – that are procured at the behest

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[47] Markusen, Michael Oden, and Johnathan Feldman, *Technology Review*, Jully 1995 p.6-7
[48] Mary Ellen Kelley and Todd Watkins, "In from the Cold: Prospects for Conversion of the Defense Industrial Base," *Science* 268, April 1995 p. 531
[49] Judith Reppy, "Dual Use technology- Back to the Future" in *Arming the future : a defense industry for the 21st century,* Ann R. Markusen and Sean S. Costigan ed., (New York : Council on Foreign Relations Press, 1999.) p.275

of the government for specific functions, tools that were otherwise accessible in the open market. However, talk of "dual use" implicitly recognizes that the strict separation of military markets from civilian ones was breaking down, especially when considering the development and manufacturing on the lower tiers.

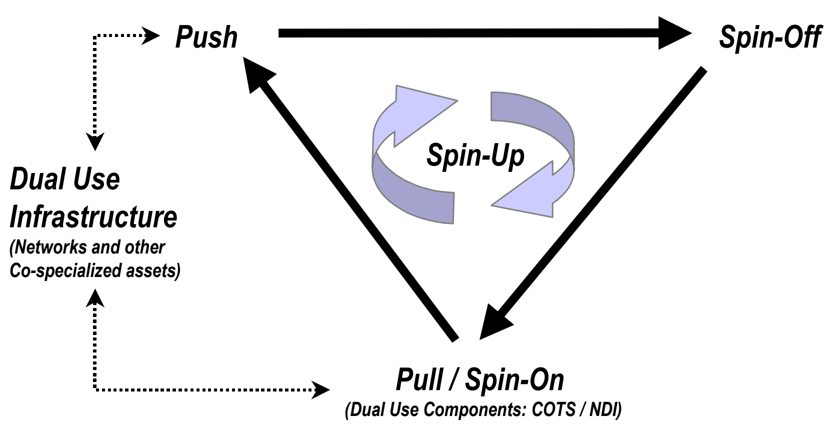
Commercial-Off-the-Shelf, Dual Use and Technology Pull

Commercial manufacturing innovation and scales of production have always made important difference in war since the beginnings of the industrial revolution. Napolean, for example, reduced the number of gun calibers from 17 to 4 in an effort to expand production of cannon; and Colt introduced interchangeable parts in the manufacture of firearms, greatly improving scales of production and product maintenance. Following Napolean's invention of *leve en masse*, attrition became the main characteristic of war, and industrial production capacity mattered almost as much as military strategy. The US military for generations relied a great deal on generic products produced by what we could characterize now as a "non-defense" industrial base. The American Expeditionary Force took commercial trucks right off the assembly line to France in 1917 and the famous C-47 World War II transport aircraft was an olive green version of the commercial workhorse- the Douglas DC-3. Nowadays there are very few examples of final product "dual technologies." The most popularized examples are imaging satellites and GPS; and each owes their public visibility to their use by business and consumers, and the impact they have had in the two Gulf wars, the Balkans and Afghanistan. GPS and imaging satellites are products that journeyed in the opposite direction of most technologies these days, from complete military systems to commercial spin-offs, and they have attracted a great deal more attention than the more mundane technology transfers that are happening in intermediate production level.

Technology transfer between the commercial sector and the military can be characterized by the distinction between technological push and pull. Technology push is essentially the military creation of new innovations to meet particular needs, which are usually defined by the doctrine of the military services. In the case of technological pull, a technological advance emerges first, one that provides inspiration for the development of weapon. According to a study by Lauren Holland, a vast majority of complete weapon systems procurements are pushed, with the most prominent exception being the cruise missile, ironically itself a precision strike weapon. According to Holland, many technological requirements are written in reference to already existing military capabilities that requires extension beyond mere modification, usually in order to fill gaps the military fears adversaries may exploit in wartime.[50]

Figure 2 illustrates the continuum between technologies whose innovation is being driven by markets and adopted by the military (*Technological Pull* or *Spin-On*), and those technologies that were created by the military and have been adopted by the commercial sector (*Spin-Off*).

Figure 2: Technological Pull vs. Push



In figure 2, a critical distinction is made between *Pull* / *Spin-On* and *Dual Use*: one between the dual use components, such as "commercial-off –the-shelf" (COTS) electronics, and *Dual Use Infrastructure*, such as communication and sensor networks that are becoming vital channels upon which both military and commercial applications depend. The relationship between *Dual Use Infrastructure* and military *Push/*commercial *Pull* is bi-directional, that is that both the military and the commercial world at times determines the technological trajectories of dual use infrastructures, while at other times is guided by them. For example, In the case of GPS, the Air Force must both direct the procurement of future versions of the system with two broad categories of users in mind: the military planning and warfighting community, and the much larger civilian user community. Other dual use infrastructures, such as communications networks, are

[50] Lauren Holland, *Weapons under Fire. (*New York : Garland Pub., 1997). p. 124

more influenced by the demands of commercial end users, with the military applications being an afterthought. Commercial satellite imaging assets are often used to support the surges in military demand, and in some cases, the military's influence on the use and evolution of the infrastructure is nearly the same as that of any other customer.

Viewing military technology as a subset of a larger base of technological research and development implies that transfers between them are often complementary. There is a cycle of innovation, in which technologies derived from basic military research and development cross over to find success in the commercial world, only to cross back into defense. For example, Oracle, the world's largest software company was born out of the "Oracle project," a government research program exploring the use of relational database management systems.[51] Pursued by both the military and commercial firms these kinds of technology "spin-ups" are especially common in the information technology arena, as both military and civilian producers attempt to learn from the others designs and implementations.

Dual Use, Acquisition Reform, and Force Transformation

The spin-on phenomena, the use of COTs and Non-development Items (NDI) in military procurements, has its origins in two trends: 1) as military budgets were slashed in the 1990's, some Pentagon planners saw COTS acquisition practices as a way to create significant savings in procurement, hoping to apply the difference to support force modernization; and 2) larger and more dynamic commercial markets were driving the development of technologies that were superior to those the military were trying to develop, especially in the area of information technology and telecommunications. In the 1990's, defense planners began to explore how technologies that were not native to the defense sector could be hardened and integrated into military systems, shaving costs while providing a state of the art boost to traditional weapons platforms. For this group, used *dual use* meant leveraging COTS.

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[51] *Oracle 9i, a Learners guide*, http://www.osborne.com/products/0072192798/0072192798_ch01.pdf

COTS and NDI movement were in part a reaction to the over-specification of requirements in military procurement. When military technologies were more advance than commercial ones, military specifications in general were superior to commercial ones. After a time, as the state of the art in many technological categories shifted from the military to the civilian sector, commercial specs became more rigorous, but because of bureaucratic inertia were, for the most part, not adopted by the military. This is partly because military specifications were a valuable tool to measure contractor performance, and because of the prevailing rationale that military procurement items required longer product lives and greater ruggedness in order to withstand the rigors of combat. The problem is that such specifications greatly increased the price of procuring even simple items, and created huge disincentives for commercial firms to enter the defense market.

> One of the primary problems with government specifications is that they do not always take into account commercial sector processes, often resulting in the need for a separate production capability for defense goods, with the cost for that separate facility being tacked on to the price of the product procured. Besides creating extremely expensive, small quantity prices for DoD goods, the inability to utilize best commercial practices actually has the perverse effect of introducing inferior contractors-which results in frequent accusations of contractor fraud, waste, abuse. [52]

There is a cultural bias against commercial products as the military had been used to solutions customized to their needs. Military planners loose patience with the private sector “concensous method” in developing industry wide standards, as well as fear the loss of control of the procurement requirements building process.[53] Those program officers who do look to integrate COTS, however, are getting better at measuring cost performance trade-offs that must be made.

As commercial components, although significantly less costly in principle and, in some cases, the state of the art, usually cannot meet strict reliability requirements for systems that must withstand much higher levels of stress and use. Thankfully, systems engineers are finding innovative solutions in maintaining integrity and operability of such equipment in military

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[52] Debra van Opstal, I*ntegrating Commercial and Military Technologies for National Strength: An Agenda for Change.* Report of the CSIS Steering committee on Security and Technology. (The Center for Strategic and International Studies, Washington D.C.) p.42

[53] IBID, p. 47

environments. Managing the obsolescence of components and sub-systems is an integral part of using COTS, a process that has become known as life-consumption monitoring.[54] For example, a commercial subsystem, not hardened to the rigors of operating at high temperatures for long periods of time may need to be swapped out more often than a one whose design is driven less by performance and more by ruggedness. At the heart of life-consumption monitoring is the application of the “physics of failure and error” which identifies dominant failure modes and locations: prior to build, allowing for reliability predictions to be made at the design stage. The process has been made easier by the development of computer-aided life cycle engineering systems.

Where the government has not been able to meet commercial manufacturers half way through life cycle engineering, it has used its market and political power, to influence commercial designs they see as promising for military applications. For example, as one of the largest consumers of computer display technology, the US Department of Defense convinced Japanese flat panel display (FPD) manufacturers to incorporate some of its requirements into its designs, partly by attempting to midwife a strategic alliances between US equipment producers and Japan’s well financed South Korean competitors that were preparing to enter the global FPD market.[55] For other technologies, since the Department of Defense is the largest single consumer of technology anywhere, it has been able to use its market muscle to squeeze commercial suppliers on not just cost, but also technology features and quality.

To understand why “dual use” technologies appear so prominently, the dynamics of commercial markets must be compared with the same processes taking place in defense research, development and acquisition. The dynamics of innovation in commercial and defense industrial markets are similar in that they both feature a pre-paradigmatic phase of “experimentation,” followed by consolidation around a particular set of technologies, each with distinct feature sets and production processes. Dual use technologies, either on the component level, or the upper tier “whole system level,” will continue to play a larger role in defense

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[54] George Leopold and Brian Fuller, “Department of Defense Demands more Net-centric tools” *EE Times*, December 27, 2001

[55] Jay Stowsky, “The History and Politics of the Pentagoin’s Dual-Use Strategy” in Arming the future : a defense industry for the 21st century, Ann R. Markusen and Sean S. Costigan ed., (New York : Council on Foreign Relations Press, 1999.) p.142

acquisition, especially in the area of information technologies. The 'information content" of advanced weapons is increasing with every generation of weapons, to such an extent that over a third of the cost of an advanced fighter aircraft is made up of electronic components and for future generations of aircraft, the figure is expected to increase to more than 50%.[56]

As COTS is becoming a greater part of defense procurement, systems integration is becoming a critical skill driving innovation in weapons systems. Of the nine categories of dual use goods in the Wassenaar Arrangement on Export Controls, the first global multilateral arrangement covering both conventional weapons and sensitive dual-use goods and technologies, five are information technology based.[57] The highest value added to most new weapon systems in the future will be in electronics that are part of a larger base of technology designed to be more *integrate*-able, for lack of a better word. That is, they are platform technologies utilizing open interfaces designed to make integration with other systems easier and faster.

Systems Integration and Platform-centric Innovation

In order to understand how technology pull is becoming more and more important, it is helpful to examine how commercial technologies evolve through experimentation in the market place, and how economies of scale and scope are introduced that put huge premium on systems integration of component dual use technologies. James Utterback, in his book *The Dynamics of Technological Innovation*, divides technological innovation into three phases: Fluid, Transitional, and Specific. The Fluid phase is a period of technological experimentation, the transitional period is a period of consolidation around a specific design, and the specific phase is one of the reaping of economies of scope and scale. The Utterback model is described in figure 3 below, and shows

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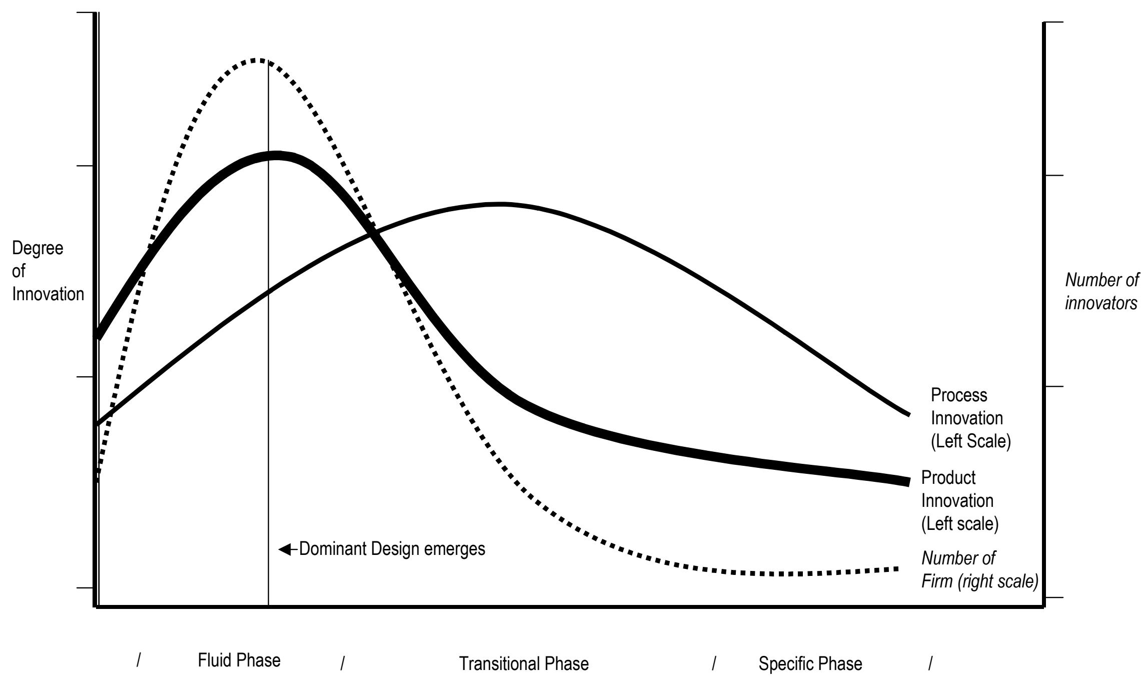
[56] Debra van Opstal, I*ntegrating Commercial and Military Technologies for National Strength: An Agenda for Change.* Report of the CSIS Steering committee on Security and Technology. (The Center for Strategic and International Studies, Washington D.C.) p. 7

[57] see http://www.wassenaar.org/list/wa-list_02_tableofcontents.html for the list. Thirty-three co-founding countries set the WASSENAAR agreement in operation September 1996. The arrangement was designed to prevent destabilizing accumulations of arms and dual-use goods and technologies by establishing a process of transparency, consultation and, where appropriate, encouraging national policies of restraint, and by promoting greater responsibility and accountability in transfers of arms and dual-use goods and technologies.

how the number of firms in the industry falls as a particular technology matures and process innovation shifts from product to process (manufacturing) innovation.

Figure 3: Utterback Model of Technology Innovation



For any given innovation, the fluid phase is characterized by a great deal of experimentation with product design and operational characteristics among technology competitors.[58] A good example of the fluid phase is found in the early years of the automobile industry, when a bewildering variety of cars -including some electric and steam powered prototypes- were driven from the workshops of more than a dozens of manufacturers. Even military innovations have their fluid phase -- for example, the creation of the main battle tank followed the same path as the automobile, with the British, French and German's all developing competing designs. In the fluid phase, a new product technology is often "crude, expensive and unreliable, but it is able to fill the

[58] James Utterback, *Mastering The Dynamics of Innovation*, (Harvard Business School Press, 1994). p.13

function in the way that is highly desirable in some niche markets."[59] This consolidation of features into a single dominant design is usually the result of such experimentation within the niche.

> The dominant design drastically reduces the number of performance requirements met by a product by making many of those requirements implicit in the design itself. Thus, few today would ask whether a car had an electric starter and electric windshield wipers, whether a typewriter could produce upper and lower case letters, or whether personal computer has a built-in disk drive, though these were unique features and models that preceded the dominant design. Today, these features are implicit in designs that the market expects and that all producers find themselves compelled to emulate. They are no longer serious issues nor are they advertised as advantages of one or another manufacturer's product.[60]

In the case of defense industrial competition, the competitors are often not firms, but other countries. Competing against German designs in WWI, the French industrial giant Renault built the FT-17 tank, which was to become the dominant design for the tank. It was most conspicuously differentiated from its competitors by its use of a top mounted turret that could traverse left and right—a feature taken for granted today. After a dominant design emerges, innovation shifts away from primary product features to ancillary ones. For the tank, for example, after the fundamental feature definition of a tank congealed, engineers went to work on improving the powertrain, armor and guns. What had been a niche technology gained ground among the mainstream military corps. As the dominant design emerged, manufacturing was ramped up in most of the major military powers.

In the "transitional phase" major product innovation slows down and the rate of major process innovations speeds up. And at this point, product variety begins to give way to standard designs that have proven themselves in the marketplace. Firms that have not adopted the dominant design begin to fall out and transitional phase manufacturers begin to compete on cost and minor differences in product features. Product design becomes rigid as manufacturing becomes less flexible, as some components of automation take shape. Even some firms that do embrace the dominant design and are technically competitive fail in the long run because they do

[59] IBID, p. 92
[60] IBID, p.26

not possess the capacity for process innovation in manufacturing, marketing and distribution. The creation of a dominant design advantages firms that are able to sustain innovation in manufacturing and other ancillary process improvements.

In the transitional phase, attention also shifts from basic design to product architecture and interfaces, and manufacturing is set up to reap not only economies of scale, but also economies of scope. Transitional phase firms attempt to leverage process innovations across to other product lines in the form of product portfolios. Product portfolios, a series of products that meet the needs of different customer value networks, take advantage of process innovations in the transitional phase by sharing common manufacturing systems and parts. “Product platforms” often begin to evolve in the context of the dominant design, and firms attempt to leverage competencies in manufacturing and design across products by utilizing modular subsystems and interfaces.

> Product platforms capable of accommodating new component technologies and variations that make it possible for firms to create derivative products at incremental cost relative to initial investments in the platform itself. That is possible because the fundamental subsystems and interfaces of the platform are carried forward across derivative products. Since the costs associated with the elements carried forward are essentially sunk costs, only the incremental costs of creating variations to them accrue to the derivatives. Typically, these incremental costs are small fraction of the cost of developing the original product platform, providing what we call "platform leverage." Product platforms can also improve development cycle times of derivative products by facilitating a more streamlined development process and more frequent model changes.[61]

From a product platform, a stream of ancillary features, or derivative products can be integrated or created without returning to redesign of the lowest common elements of a product. For manufacturers, product platforms are capable of accommodating new technological components and advances in materials as they mature and come online. For consumers, product platform interfaces are useful as well: internal interfaces for components increase the ease of maintenance, while external interfaces to other products allow the end user to combine the product with others to achieve product functionality otherwise not present in any given product

[61] Marc H. Meyer and Alvin H. Lehnerd, *The Power of Product Platforms* (New York: The Free Press, 1997) p. 41

individually. For example, the architecture for personal computers was adopted by manufactures when they developed and manufactured servers. A product platform, with modular design and interfaces, is expanded and what might have been a single niche component of a larger system becomes differentiated again along a different axis of design and functionality-- this time to serve other categories of users.

Eventually, as innovation in both product functionality and inter-product compatibility declines, the market continues to mature. Finally in the "specific" phase, the rate of major feature innovation dwindles for product, architecture, and process to small incremental steps forward. In the specific phase, industries become extremely focused on cost, volume, and capacity, and have developed highly specialized manufacturing infrastructure that is highly automated and highly inflexible.

Technological Maturity and Ease of Integration

Innovation in the transitional phase and the competitive incentives to create internal or external product architectures vary by firm and by market. Architecture itself is becoming a prominent prime feature of most end products as well as intermediate ones, and this trend is reinforced by the existence of open architecture in computing and communications networks. The creation of "genetic" algorithms, object-oriented programming, and modular architecture of information systems has meant that incremental technical changes to a system are easier and less disruptive to users. Modularity is also being built into military hardware as well allowing technologies to be clustered and frequently updated on maneuverable platforms. For example the Navy's command ship, the USS Coronado was designed from the start to be re-configurable, allowing Navy experimenters to insert new subsystems. Most aircraft are essentially a platform of subsystems managing target acquisition, fire control, guidance, and of course flight control. Weapons are becoming high value added system of systems, as platform architectures grow at many levels of design, engineering and manufacturing.

At the component level, creation of dominant designs and product platforms is important in fashioning a division of labor that takes advantages of different firms comparative strengths in innovation and manufacturing. According to Marc H. Meyer and Alvin H. Lehnerd, it is difficult to write, execute, and enforce complex development contracts, particularly when the design of a new product is still "floating."[62] Therefore a degree of certainty must be achieved in a design for systems engineering and subcontracting of key components can occur. Utterback argues that even radical innovations are often based on the synthesis of well-understood technical information or components, and often seemingly obvious technologies evolve slowly step-by-step, existing in an embryonic form for many years before they become commercially significant.

Technological readiness levels are also often the main determinant of whether a technology is militarily useful. In the 1980's technologies in military applications pushed by the services in many instances stood beyond the leading edge; that is, they were enormously risky to the programs they purported to support, and in some cases seem to justify. The classic example was the B-1 bomber, where core technologies were developed concurrently with their integration into the weapon systems, leading to many disconcerting results. For example, the aircraft's threat-warning system and radar-jamming system would jam each other, the result being that the pilot flying the aircraft had to choose between protecting himself or carrying out his mission.[63] The hard lessons from the 1980's inspired a serious examination inside the defense community of how emerging commercial technological innovations could be integrated piecemeal to avoid such troubling results. A General Accounting Office report summarizes the new line of thinking, one that emphasized technological maturity before systems integration.

> ….leading commercial firms launch a new product later than DOD, after technology development is complete. They refer to this point as the beginning of product development, the point at which they commit to developing and manufacturing the product. Typically, technology is still being developed when weapon system programs are launched; the point at which a weapon system is far enough along to compare to a commercial product development is likely to be at or after the start of engineering and manufacturing development.[64]

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[62] Marc H. Meyer and Alvin H. Lehnerd, *The Power of Product Platforms* (New York: The Free Press, 1997) p. 41

[63] "Big Dreams Still Need Oversight: Missile Defense Testing and Financial Accountability are Being Circumvented," July 16, 2002, Project on Government Oversight http://www.pogo.org/p/defense/do-020701-bmd.html

[64] Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes, The General Accounting Office, July 1999 GAO/NSIAD-99-162 www.gao.gov/archive/1999/ns991620.pdf

The GAO report studied 23 different technologies and weapon programs and indicated that technologies demonstrating a high level of maturity before being incorporated into product development programs puts those programs in a better position to succeed. In defense, the degree of technological certainty is a key determinant of success of a given innovation.

Incentives in creating "System of Systems"

The dynamics of technological innovation in the commercial sector is more continuous, where in the defense sector success is more discrete and controlled, with fewer punishments for poor design or lack of economies of scale and scope. Traditionally, technological innovation in defense was carefully planned, and a small number of "traditional" contractors competed on the basis of fairly detailed requirements. These firms were in some sense protected from their failures in order to preserve continuity in the defense industrial base, enough continuity so that production could be ramped up quickly in the event of war. This worked sufficiently well when threats were easily defined and technological advance was steady and predictable. As the pace of technology quickens, however, advances will begin to outstrip the Department of Defense's ability to write requirements, especially given the lack of a single strategic enemy. Ultimately, technology "push" will likely become less prominent relative to commercial "pull." To some degree, this is happening now. For example, responding to the September 11th terror attacks, the Pentagon took the unusual step of issuing a solicitation for industry concepts to fight terrorism. This "broad area announcement" provides a glimpse of how the speed of recent events has also driven the Pentagon to attempt to imbue defense with a new culture of acquisition, one more entrepreneurial, less risk averse, and less top-down requirements based.[65]

The Department of Defense has also tried to embrace the creation of joint warfare doctrine, and has created organizations to push the military services to create "joint" systems that can create synergies between technical assets, especially in the areas of command, control,

[65] George Leopold and Brian Fuller, "Department of Defense Demands more Net-centric tools" *EE Times*, December 27, 2001 The authors on the COTS transformation: "One consequence is that planners will seek to take the decade-old drive to adopt commercial, off-the-shelf (COTS) technologies and expand it. The networking revolution that has transformed global industry will be applied to the U.S. force structure in new ways that will affect everything from procurement rules to intelligence collection and dissemination, officials said."

communications and reconnaissance. Technical architectures are one of the prime innovations that have a bipolar orientation, toward both product and process advances. Architectural innovation reinforces itself by making possible future product and process innovations through the creation of interfaces that can leverage other technologies. In this sense, the Department of Defense has begun to belatedly recognize the fact that subsystem interfaces are strategic. What Joint warfare doctrine seeks to achieve are both smooth technical and organizational interfaces, ones that allow an innovator to leverage a common "market" understanding, common product technologies, and a common set of highly automated production processes.[66]

Clearly defined interfaces between subsystems of products, and between products and users, provide product designers with the degrees of freedom needed for the rapid and cost-efficient creation of derivative products and functionality on the margins. Architecture implies that development can occur on several levels: once at the architecture level and several times on the subsystem level. It implies a moving target, that an architected product with interfaces can evolve as the number of subsystems are added or subtracted. Architecture implies iterative development, and the Department of Defense has put its faith the *spiral development*, a engineering concept developed at Carnegie Mellon's Software Engineering Institute. It is attractive for acquisition planners because of its triple competency: concurrent development, architectural innovation, and risk management. Spiral development model is different from previous efforts in concurrent development in that it is risk-centric, in that it puts a very high premium on technological readiness.

> [Spiral development] is a risk-driven process model generator. It is used to guide multi-stakeholder concurrent engineering of software-intensive systems. It has two main distinguishing features. One is a cyclic approach for incrementally growing a system's degree of definition and implementation while decreasing its degree of risk. The other is a set of anchor point milestones for ensuring stakeholder commitment to feasible and mutually satisfactory system solutions.[67]

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[66] Marc H. Meyer and Alvin H. Lehnerd, *The Power of Product Platforms* (New York: The Free Press, 1997) p. 2
[67] B. Boehm, *Spiral Development: Experience, Principles, and Refinements* (CMU/SEI-00-SR-008) Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University, 2000.
http://www.sei.cmu.edu/cbs/spiral2000/february2000/BoehmSR.html

Also know as “evolutionary acquisition,” spiral development is, according to retired Vice Admiral Arthur Cebrowski, head the DOD's new Office of Force Transformation, "…a superior way to do things than to forecast a need 15 to 25 years hence, freeze a design and then make it fit into the reality that emerges," Spiral development requires much higher levels of technological maturity, and a clear division of weapons acquisition from technology development.[68] The new paradigm for acquisition has four major pillars: 1) a huge premium on speed -- putting systems out before the technology becomes obsolete, 2) separation of technology from development, and the integration of mature technologies from a diversified technological base, 3) an abandonment of strict requirements, inclusion of commercial technology where suitable, and emphasis on prototypes and experimentation. 4) the emphasis on architecture and integration of weapons into a “system of systems.”

The Transcendence of Telematics

According to Jeffery R. Cooper, the US pursued three distinctive approaches to countering the Soviet threat during the Cold War. The first was the incremental improvement in systems across the board to prevent the Soviet Union from exploiting gaps in capabilities. This created, for example, generations of aircraft that could out-maneuver Soviet counterparts, and tanks to out-run and out-gun Warsaw Pact columns. The second approach was the creation of revolutionary scientific breakthroughs, technologies such as ‘stealth’ designed to “leap” over Soviet defenses. The last approach was the integration of communication technologies, navigation systems and sensors to enable tracking and automated targeting from tanks, ships and aircraft. This last approach was key for the US to offset the Soviet Union’s quantitative advantage in the battlefield, and the main impetus for what is now called the “Revolution in Military Affairs.”

Ultimately, the US “qualitative” advantage over the Soviets was achieved through a more heterogeneous technological base, with rigorous competition between different technological

[68] *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes,* The General Accounting Office, July 1999 GAO/NSIAD-99-162 p. 61

solutions in both commercial and defense “markets.” Coupled with the creation of economies of scale and scope, primarily through the procurement of operational subsystems co-specialized to common weapons platforms, the US was able to create network effects in capabilities- that is the value of a weapon system is a function of the number of nodes, or interfaces it has to other systems . Cooper argues that military innovations the US has pursued have fallen into three phases: the first two being incremental, while the last one being revolutionary and disruptive. The first is a technology solution acquired to meet a very specific, well-defined need, the second is analogous Utterback’s transitional phase, as the utility of the application is widely recognized as a “superior good,” and users and application developers pile on board to the technological concept. The last phase is transcendental, that is it moves beyond any single technology and focuses on the whole network of complementary assets. It is primarily an intangible, a doctrinal or strategic innovation, and like telematics, is focused on how technologies leverage each other.

Dual use technology is most prominent in the transcendental phase, since most are not primary technologies, but intermediate ones. Telematics, the exploitation of novel interfaces between what are quickly maturing, militarily significant products --geo-positioning sensors, GIS, satellite imagery and communications networks. The reconciliation of commercial benefits of telematics to the needs of defense, however, requires a strategy that not only addresses the control of critical space-based infrastructure, but also examines what other, smaller technological resources and competencies need to be monitored.

TELEMATICS, DUAL USE, THE PROLIFERATION OF WEAPON GUIDANCE SYSTEMS

Defense planners saw “dual use” as either an opportunity or a threat, but rarely as both. Those who saw it as a threat appropriated the term “dual use” in its policy debates over weapons proliferation. Their concern was that the globalization of the western technological and manufacturing base would make it easier for “rouge states” to construct devastating conventional and non-conventional weapons that would threaten US forces in theatre and even civilian populations at home. Although most of their emphasis has been on the spread of weapons of mass destruction to lesser-developed countries, they have also warned of the proliferation of advanced navigation and targeting systems to older more technologically sophisticated adversaries such as China and Russia. One of their greatest fears is that the loss of the GPS monopoly to new space based radionavigation systems such as Galileo, and the revived Russian constellation GLONASS, along with the spread of commercial telematic equipment and applications, will slowly spell an end to the US comparative advantage in precision strike weaponry.

The question is whether it is possible to achieve the economic benefits of telematics without seriously compromising America’s technological advantages on the battlefield. Teece argues that given the overwhelming complexity of most new technological innovations, nearly all of them require a host of assets specialized for their production or use, and that very few firms or even countries can possess all of them at any one given time. Such assets are largely informational, either networks, specialized manufacturing tools or computing subsystems, and are strategic chokepoints that can be targeted preemptively or inhibited post hoc to minimize their military utility in time of war. The last chapter argued that most new innovations for military systems will be powered by advances in sensor arrays, computing systems, and software that come from a mix of technologies developed in commercial and defense industrial markets. This chapter focuses 1) the historical progress of on-board and off-board navigation tools and precision guided weapons, and 2) how the proliferation of advanced targeting systems that depend on satellite positioning can be minimized.

Inhibiting proliferation or utility of weapons requires looking at them from a "whole system" perspective, one that takes into account key engineering competencies, organizational innovations, and co-specialized networks. Derek W. Smith, in an article entitled the *Double Edged Sword, Controlling the Proliferation of Dual-Use Satellite Systems*, summarizes the various combinations of actions that can be taken either to *protect* forces against new weapons, versus initiatives that can be taken to *prevent* their diffusion in the first place. The key distinctions he draws can be seen in figure 4.

Figure 4: Protection versus Prevention Strategies[69]

	Can Prevent	**Cannot Prevent**
Can Protect	Strategic Control	Very Little Control
Cannot Protect	Strong Export Controls	Dominate the Market

Smith's matrix illustrates the broad outlines of strategy in managing proliferation. If you have the power to prevent diffusion of military useful technologies, then strong export controls are called for, otherwise, a protection strategy must be employed, either directly through pre-emptive or defensive countermeasures, or indirectly through economic influence in the marketplace. Smith admits that there are many underlying elements to proliferation that intermingle, but as a generalized map his matrix is helpful.

Systems Integration as a Barrier to Proliferation

Teece argues that in times of fast technological change, advances are produced so rapidly that it is unlikely that a single company has the full range of expertise needed to bring advanced integrated products to market in a timely and cost effective fashion. Along the same

[69] Derek W. Smith, "Double Edged Sword, Controlling the Proliferation of Dual-Use Satellite Systems," *National Security Studies Quarterly*, Volume VII, Issue 2 (Spring 2001). P.34

lines, as some firms cannot be entirely independent from others, many countries find it extremely difficult to muster all of the competencies and resources to become “independent” in a particular field of technology. This appears to contradict the fundamental assumption of weapons proliferation: technological knowledge is easily exploitable, and inventors must reconcile themselves to the fact that they will often lose their technological advantage in a short period of time. After all, the commercialization of advanced technology implies that nothing can stop a country that seeks to build sophisticated weapons from buying parts on the open market and constructing the systems themselves. Teece, argues, however, that “copy cats” are especially vulnerable to dependencies that are manageable in a commercial context, depending on the degree of technical and legal barriers to exploitation. He argues than an innovator “could attempt to access these [co-specialized] assets through straightforward contractual relationships (e.g. component supply contracts, fabrication contracts, service contracts, etc.). In many instances such contracts may suffice, although it sometimes exposes the innovator to various hazards and dependencies that it may well wish to avoid.”[70] Teece argues that this is especially true of information technologies.

> As technologically progressive industries mature, and a greater proportion of the relevant co-specialized assets are brought under the corporate umbrellas of incumbents, new entry becomes more difficult. Moreover, when it does occur it is more likely to involve coalition formation very clearly on. Incumbents will for sure own the co-specialized assets, and new entrants will find it necessary to forge links with them. Here lies the explanation of the sudden surge in “strategic partnering” now occurring internationally, and particularly in the computer and telecommunications industry.[71]

Because of the need to control or contract specialized assets which a firm or country may not have, and given that the component of experience and knowledge native to a particular technology may not be readily available, weapons technology may not even transfer within a country between technological domains.[72] Looking at proliferation from a macro perspective, control of key specialized economic assets, such as manufacturing capacity, or co-specialized

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[70] David J. Teece,“Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy.” The Competitive Challenge, ed. D. Teece, June 1986 P. 294.
[71] IBID, p.304
[72] Ann R. Markusen and Sean S. Costigan ed., *Arming the future : a defense industry for the 21st century*, , (New York : Council on Foreign Relations Press, 1999.) p. 404

ones such as critical information networks are one part of the equation. The second part is less tangible, and depends on “knowledge economies,” competencies in exploiting technology for particular ends. In this sense, systems integration is a key comparative advantage and a barrier to proliferation.

> The current anxieties about the “cyber threat” suggest the vulnerability inherent in military reliance on commercial information technologies. The global culture of the internet, along with the global spread of chip manufacturing, provides a common (civilian) space for information technologies which are arguably the most critical dual-use technologies today. Systems integration is a skill that the US has pioneered and still retains a considerable comparative advantage. And in each succeeding generation of weapons, integration skills are becoming more and more important.[73]

The application of science to solve specific problems in some ways is even more difficult than creation of basic scientific discoveries themselves, especially given that engineering must solve the problem of production and manage the costs associated with it. Just as Sassen argued that economic modes of production are shifting to services, most technological innovations are process oriented and largely intagible, requiring high levels of integration of tacit knowledge. In figure 5, the “cloud” represents those elements of production that are the least tangible, and therefore the hardest to reproduce from scratch.

[73] IBID p.412

Figure 5: Industrial Knowledge Map

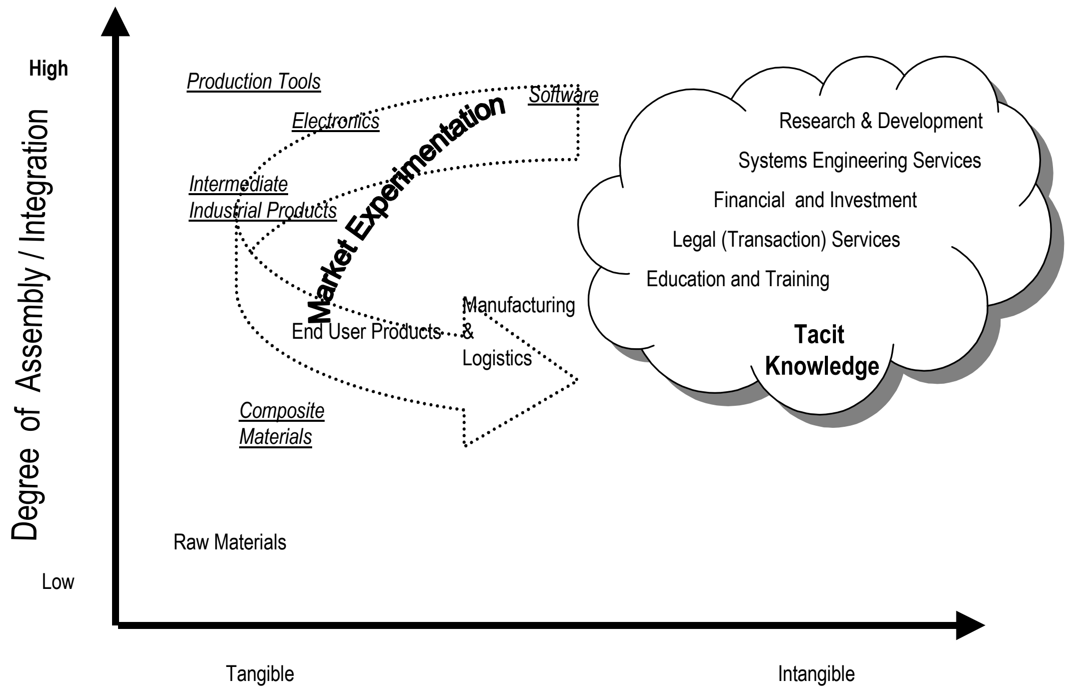

Figure 5 shows that the systems integration "barrier" is really deeper than the tacit information related to any particular technology, but if a complicated function of a whole range variables, specifically markets, services and knowledge infrastructures that facilitate experimentation and drive technological trajectories.

In trying to apply Smith's two-by-two matrix, one must delve much deeper into an given country's competency in a particular innovation or the range and depth of its portfolio of tangible and intangible assets needed to produce a given weapon system. In order to understand the potential for dual use telematic technologies to be forged into effective conventional precision strike weapons, it is helpful to look at the history of the development of navigation instruments and precision strike weapons, and how the technology foundation for such weapons will likely evolve.

The Evolution of Precision Strike Weapons and Navigation War

In 1915 the Navy gave Sperry Gyroscope a three thousand dollar contract to build the unmanned Kettering "Aerial Torpedo"—the earliest manifestation of the cruise missile. The Aerial Torpedo was a catapult-launched Navy biplane with an autopilot (a gyroscope attached to the controls that allowed the craft to maintain level flight against the force of shifting air currents). The Autopilot would keep the Arial Torpedo on a straight and level course, and a timer would shut off the engine at the proper moment to drop the plane on its target.[74] The Germans created the V-2 rocket in World War II and used it against the British with devastating effect, but it was not until the 1970's did the US successfully applied the V-2 concept with the introduction of the Regulus, the precursor to the current Tomahawk cruise missile.

As quickly as guidance equipment was added to aircraft and munitions, methods to counter such devices were formulated. The first successful guidance countermeasure was created in World War II, when the British learned of German "navigation" beacons used to guide their bombers to their targets in Britain. The Luftwaffe had developed radio navigation beams that allowed a pilot, listening in on a headset, to hear a buzzing sound when his aircraft wandered off course. An additional beam bisected the flight path to mark the target. The British learned of this and used a combination of countermeasures to fool the system, while at the same time concealing from the Germans the fact that their system had been compromised.[75] Another countermeasure was to make potential targets mobile. Autopilots, by feeding back changes it detected in flight path to the control surfaces of an aircraft, solved the problem of stabilizing aircraft in flight, and fixed radio beacons could let human or computer pilots find and hit immobile targets. If the target moved, however, these systems were useless, because they could not actively update its feedback loop to take into consideration the changing position of the target. With the introduction of heat or radar seeking missiles, "guided" airborne weapons could update

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[74] *A Brief History of Precision Guided Weapons*, http://www.tfcbooks.com/special/missiles.htm. In its first test flight, the Arial Torpedo's engine cut out early and the plane plunged into the sea.

[75] Bruce Berkowitz, *The New Face of War: How War Will Be Fought in the 21st Century* (New York : Free Press, 2003), p 27.

their feedback loop for changes in target reference. If targets tried to evade a tracking weapon, updates to the autopilot could arrive faster than the time it took for the targets to take evasive action.[76]

Over the last fifty years, the precision of aerial attack has grown by several orders of magnitude. For example, in all of 1943 the entire 8th US Air force attacked about fifty target sets. During Desert Storm, the coalition struck 150 individual targets in the first day of fighting. In the not so distant future it may be possible to engage 1,500 targets within the first hour, if not the first minutes, of a conflict.[77] Instead of calculating aircraft-per-target ratios, air-tasking officers quantify suitable target-per-aircraft ones instead. The maturity of the US command, control, surveillance and reconnaissance systems has recently offered forces the capability to lock onto moving objects and to flash guidance corrections to weapons on their way to target. In fall of 2002, U.S. pilots demonstrated the ability to drop a bomb and then continuously update the weapon's aim --while it was falling--with enough precision to consistently hit within lethal distance of a moving target, even as it maneuvered aggressively among vehicles, foliage and obscuring terrain features. The Affordable Moving Surface Target Engagement (AMSTE) system integrates a number of new targeting algorithms, data links, two long-range radars and GPS navigation—and could be installed on five E-8 Joint-STARS ground surveillance radar aircraft and made ready for operational use by the end of 2003.[78]

A fundamental concern of US defense planners is whether commercially available technologies will enable potential enemies to greatly improve the accuracy of their weapon systems. The crucial question is how accessible value added technologies are to potential opponents who seek to build primitive guided cruise missiles (GCM) or unmanned air vehicles (UAVs). In March of 2000, Iran Aircraft Manufacturing Industries announced introduction of two new unmanned air vehicles that both use on-board GPS navigation. Evidence of Iraq's covert UAV program was acquired on June of 2002, when the US military tracked an automatically

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[76] IBID p.85

[77] Jeffrey R. Cooper, *Another view of the revolution in military affairs* (Carlisle Barracks, PA : Strategic Studies Institute, U.S. Army War College, 1994) p.17

[78] “Moving Targets Vulnerable To Radar/Weapons Mix Networking airborne sensors allow warfighters to consistently track and strike maneuvering vehicles” *Aviation Week & Space Technology*; New York; Dec 2, 2002; David A. Fulghum;

piloted UAV during a flight from its Samarra East air base around 100km north of Baghdad.[79] Furthermore, US defense intelligence analysts consider these kinds of efforts as an intermediate step to development of GPS guided cruise missiles that will be able to destroy more discrete targets. Even in the short term, such UAVs will be potent platforms for the delivery of less discrete munitions, such as biological and chemical weapons.

More discrete systems may soon be appearing. Many of the components needed to build UAVs are commercially available, although not always easy to acquire. An ancillary technology such as stereoscopic satellite imagery is available commercially and can be used to generate terrain elevation maps that can be fed into primitive guidance systems. A potential enemy cruise missile, utilizing accurate terrain maps and target telemetry, and served by robust GPS enabled guidance systems could potentially wreak destruction on immobile assets in key access areas such as ports and airfields, choking off strategic logistics intake points. The long-term solution to the cruise missile/UAV threat is protection: development of interception countermeasures, such as surface and air-to-air missile systems, and "last chance" defenses such as the Navy Phalanx gun. In the near term, however, the US can counter the proliferation of crude cruise missiles and UAVs by monitoring and controlling exports of complementary navigational instruments such as accurate inertial navigation systems, and by devising a vigorous navigation war (NAVWAR) strategy that focuses on jamming GPS signals (or other GPS-like systems) in the event of war.

Digital Mastering of the "Physics of Error"

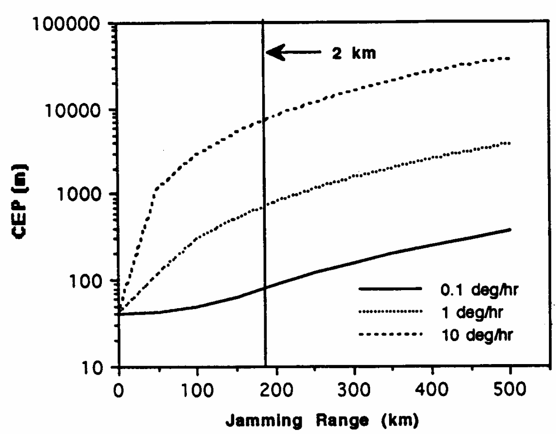
Cruise missiles/UAVs must rely on inertial navigation systems (INS), GPS receivers, or combination of both for guidance to target. Inertial navigation systems suffer from perceptible error over time, and at extended distances the drift is significant enough to offset lethality. Small, high quality gyroscopes and accelerometers (those with 0.1 degree/hour drift rate) are controlled by the Missile Technology Control Regime (MTCR), which restricts the sale of small, highly accurate INS. The Wassenaar Arrangement on Export Controls also restricts the sale of INS,

[79] Adams, Thomas K., LTC, USA (ret). "GPS Vulnerabilities." *Military Review* 81, no. 2 (March-April 2001): 10-16.

gyroscopes and accelerometers as well. Larger, accurate INS can be used but are difficult to integrate into small platforms. A report from the Congressional Office of Technology assessment argued that adapting INS originally intended for aircraft or ships for use in cruise missiles is difficult for several reasons. First, an inertial navigation package may be too heavy or too large and its performance may be degraded by a craft's high acceleration. Second, it may also be impossible to align the INS' orientation precisely enough to achieve the accuracy needed for guidance.[80]

One potential solution is the integration of a low end, commercially available inertial navigation system, with a GPS receiver that can correct for drift. Integration of imprecise inertial navigation systems and GPS, however, will not necessarily result in the accuracy needed to achieve a high level of lethality. Figure 5 plots Circular Error Probability (CEP) on a log scale against the range at which a GPS guided cruise missile is jammed for three different types of INS systems, 0.1/degree per hour, 1.0 degree per hour, and 10.0 degree per hour drift. CEP represents the accuracy and is a proxy for lethality.

Figure 6: CEP vs. Jamming Range for Airborne Jammer against GCM using GPS[81]



CEP vs. jamming range for airborne jammer against GCM using SPS.

[80] U.S. Congress, Office of Technology Assessment, *Technologies Underlying Weapons of Mass Destruction*, OTA-BP-ISC-115 (Washington, DC: U.S. Government Printing Office, December 1993)., p 229
[81] Irving Lachow, *The global positioning system and cruise missile proliferation assessing the threat*. Cambridge, Mass. : Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, 1994. p 74

Figure 5 shows that GPS guided cruise missiles with very accurate INS will be able to maintain some acceptable level of accuracy within 100 km jamming range.   A GPS guided cruise missile with a more rudimentary INS pack (10 degree/hour drift) will have a CEP of nearly a kilometer if jammed within 50km of its target.

Ironically, although susceptible to effects of jamming, inertial navigation systems can actually make GPS signals easier to acquire, while GPS receiver actively attempts to correct the INS for drift. A "tight coupling" strategy uses INS to serve as a reference for GPS, as well as GPS for INS, strengthening signal acquisition against a background of noise.

> GPS signals are at a very low level, about -130 dBm. at the receiver, and well below the noise. If it was a conventional uncoded signal, it would not be detectable against the noise, but by knowing the code the receiver gets extra gain from processing to pull the signal out of the noise. The highest processing gain is realized on a stationary receiver because it can predict precisely when the next pulse will come and tightly focus the processing over a narrow window for high gain. But a receiver on an airplane or missile has to broaden this window to allow for unexpected motions and suffers a loss in processing gain….The secret to tight coupling is that the INS tells the GPS receiver where it is and in effect turns it into a stationary device. Now the GPS can do much tighter processing and boost signal strength for more antijam resistance.[82]

“Tight coupling” is illustrative of how guidance systems require a great deal of skill in systems integration, and how these skill requirements rise in step with the growing sophistication of countermeasures. Highly sophisticated targeting systems are not black box systems, that is they are not self contained single products, but a host of tools that are integrated. Very high accuracy guidance is therefore a function thof e availability of several technologies, and the degree of technical competence needed to incorporate them into a single system. The Tomahawk land-attack cruise missile, for example, contains not only a terrain contour matching radar guidance, but also a final optical target matching system known as the Digital Scene Matching Area Correlation (DSMAC) system which compares a stored image of target with the actual target image. It is the very latest in the field of imaging technology, and the system relies heavily on software and sensor integration. DSMAC uses onboard sensor (infrared or millimetric radar) to

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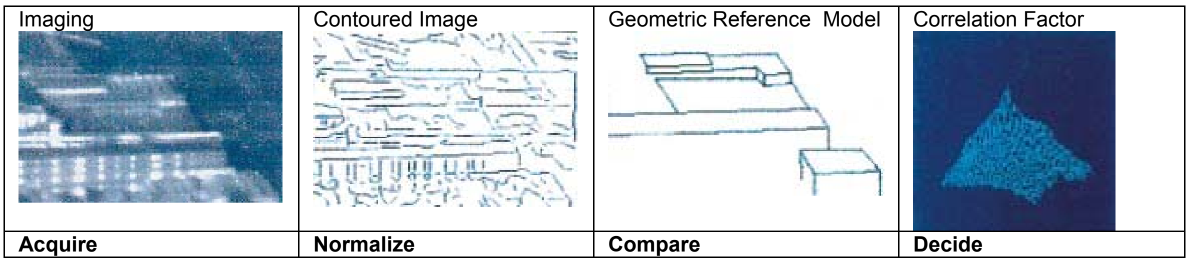
[82] “GPS Improvements Set To Help Civil Users” *Aviation Week & Space Technology*; New York; Sep 23, 2002; Michael A. Dornheim

capture high resolution images that it uses to recognize its target by comparing what it sees ahead with images stored in memory. Figure 6 shows how DSMAC can capture a photo of the target as it is approaching and through a complex algorithm correlate the surveillance sensor photo image it has just taken to a pre-determined target reference.

Figure 7: The DSMAC System Process– Correlating Image to Target Models



Newer versions of DSMAC promise to find targets through camouflaging, and can distinguish targets whose appearance has been altered as the result from damage incurred from an earlier attack.[83] "Tight Coupling" and DSMAC are both illustrative of how "precision strike" guidance systems are susceptible. They are only as good as the information that is fed to them, whether they be from external sensors, image processing computers or GPS receivers. Donald MacKenzie, in his book *Inventing Accuracy*: *A Historical Sociology of Nuclear Missile Guidance*, argues that in some sense, the degree of an inertial navigation system's accuracy is highly dependent on how it tries to achieve the result– through the brute force of the instrument or through error forecasting.

> The relative accuracy of different gyroscope and accelerometer designs is also made a more complex issue by the way the meaning of the "accuracy" of a gyroscope or accelerometer has changed over the years. As error modeling has developed, and as on-board digital computers have become more powerful, the size of the "brute" error has become less important than how well the errors of a device can be predicted mathematically. The "inaccuracy" of a missile guidance inertial sensor has become, in effect, the residual after the guidance system software has corrected for all predictable error processes. What thus has to be evaluated is not merely the device itself, but the whole network of knowledge surrounding it. If this is true for the components of systems, it is even more true

[83] Eric H. Biass, Armada International http://www.armada.ch/99-4/011.htm, accessed April 5, 2003

> for the systems themselves. In the case of unistar stellar inertial guidance, for example, we saw how a statistical model of error processes was vital to the system's functioning. [84]

Mackenzie goes on to argue that rarely do elementary unchallengeable physical laws exist to support or disconfirm evidence of a guided weapon accuracy, especially given advances in information technology and the ability of scientists to probabilistically predict errors in their own instruments. The power in American INS for ballistic missiles in the 1970's and in the DSAMC now, are in their computing capabilities. Over time, as navigation errors are better understood, and better statistical algorithms can be developed, more complex, more difficult errors can be predicted and compensated for, and over time accuracies will improve beyond what could have been accomplished through straight line improvements of existing navigation systems.

This contrasts with the soviet ballistic missile guidance program. The soviet program stayed on the straight line technology trajectory, and it tried to improve INS to eliminate "absolute" errors in the gyroscope. It is not entirely clear why the Soviets chose this approach, and McKenzie argues that some Soviet computers at the time did have the capacity to correct for errors. McKenzie speculates, however, that there was probably belief by the military that it was foolish to rely on overly complex software for operational performance, and a stubbornness on the part of Soviet scientists and engineers in their seeking to pursue smaller marginal returns in minimizing "absolute errors," as opposed to leaving them be and trying to correct for them in other ways. In some sense, for the US, the design for guidance leaped ahead through architecture, by integrating INS and computing, while the dominant design for Soviet missile guidance lay within continuous refinement of the old dominant design of INS.[85]

Systems like DSMAC certainly cannot be bought off the shelf, though the technologies may be purchased separately and integrated. The possibility that potential enemy can integrate sensors, computing hardware, targeting software and GIS query engines is well far beyond the competence of most firms in the industrialized countries, let alone in the developing world. Even

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[84] Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*, (MIT Press Cambridge 1993) p. 317

[85] IBID., p. 321, Instead the Soviets used redundant arrays of gyroscopes that used a "voting system" to average out the errors by comparing differences between each of them. Essentially the Soviets depended on an analog computer to correct for drift, while the US system used a digital one.

with a complete system, the digital “knowledge network” is a vulnerability that needs to be explored. In summary, a realistic information warfare strategy requires targeting the “knowledge network,” the interfaces between the various systems, and attacking them according to the contingency.

Prevention: Creating Transparency in Technology Transfer

A country that seeks to create precision strike weapons, however, will have to do so at great costs in terms of time and money, and will likely attract the attention of all in the international community. McKenzie makes the point that technological trajectories are less the result of entrepreneurship by technologists, but more of a function of political initiative.[86] “In the case of the Soviet Union, there was no dynamic, wider inertial industry that missile guidance could simply be drawn upon, nor any burgeoning indigenous computer industry creating ‘sweet’ technologies that present themselves effortlessly to guidance system designers.” Where there has been no scientific tradition or competency in a particular technology or related technologies, often a force outside of the scientific community must come to bear on it before it can achieve scientific or engineering breakthroughs. In the case of the Soviet Union enhanced accuracy seems to have been achieved only with great cost and considerable difficulty.[87] For a country lacking technical competency and complementary technologies, given the amount of political and economic capital that must be expended to procure such complicated systems indigenously, technology development will likely be long and drawn out, and will likely be visible in some form to the outside world, allowing US defense planners considerable advance warning.

International export control agreements can also provide more transparency into the process of diffusion. The MTCR prohibits the export of “guidance sets” capable of achieving system accuracy of 3.33 percent or less of the range (e.g. a CEP of 10 km or less at a range of 300 km), except for those designed for missiles with a range under 300 km or manned aircraft. Although larger INS packs may find their way into slower, more susceptible UAVs, smaller, more

[86] IBID, p. 334
[87] IBID, p. 335

accurate packs will be difficult to acquire for cruise missiles. MTCR includes most of the advance manufactures of sophisticated guidance sets: the United States, Japan, United Kingdom and France. Of the other producers of guidance sets, China, India, Israel, North Korea, and the Ukraine are not members of MTCR.[88]

Most likely what will occur are development of rather “dumb” cruise missiles or UAVs that utilize primitive guidance systems, are aimed at well known fixed targets and are weak enough electronically that they can be easily spoofed or jammed. If such cruise missiles could be produced in mass quantities, then a country might be able to find utility in them in striking fixed or “less mobile” targets in saturation attacks. In reality, it would probably be more realistic for most countries to attempt to circumvent export controls and purchase less capable systems from Russia or China, than to attempt to develop and mass produce their own systems.

Protection: Electronic Countermeasures vs. Interception Strategies

In the short run, the US should continue to restrict the export of advance INS packs, and should encourage other countries to do so as well. This will buy time for the US to shift their countermeasure strategy from one relying strictly on jamming to one that layers a robust missile defense on top of NAVWAR operations. Table 1 summarized the advantages and disadvantages of both.

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[88] *The MTCR Handbook*, Nonproliferation and Disarmament Fund, Department of State, 1997 p. 32

Table 1: Protection Countermeasures: Advantages and Disadvantages [89]

	Jamming	Interception
Advantages	* Inexpensive * Easy to deploy in near term	* Cruise missile/UAV destroyed * More effective at close range
Disadvantages	* Self Jamming possible * Quick GPS reacquisition possible (especially effective with advanced INS) * Hardening/Anti-Jam capabilities possible Cruise missile/UAV is not destroyed	* Take time to develop * Order of magnitude more complex and expensive * Clutter problem may make tracking difficult * Forces diverted from other missions * System vulnerable to saturation attacks

Both electronic countermeasures and interception are two specific options for countering the proliferation of precision strike weapons. Given the war is becoming more and more an massive exercise in intelligence collection and analysis –near real time surveillance of the battlespace -- there appears to be no fixed shelter from precision guided weapons. As the battlefield becomes more transparent, dispersion, covertness and stealth – essentially information armor, are the only effective protection.[90] The trend towards smaller, more mobile forces will in some sense ameliorate the impact of precision weapons proliferation when US forces arrive in the battlefield. But total mobility is not always possible to achieve along all dimensions of warfighting, and is no complete substitute for other protection measures. In order to be effective, it must be coupled with "information superiority," the ability to know everything there is to know about the theatre of battle, while denying the same information to opponents.

Over the short term, the US can focus efforts on jamming GPS signals. This will be effective given that many primitive cruise missiles/UAVs will likely be hardened against electronic countermeasures and will therefore be especially susceptible. The long run, however, will require development of systems to track and destroy craft that fall above and below the normal target profile for most anti-aircraft systems, that is relatively fast moving, or slow moving, ground skimming aircraft with smaller than normal radar cross sections.

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[89] Modified from Irving Lachow's, *The global positioning system and cruise missile proliferation assessing the threat.* Cambridge, Mass. : Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, 1994. , p. 77
[90] Bruce Berkowitz, *The New Face of War: How War Will Be Fought in the 21st Century* (New York : Free Press, 2003), p. 74, p 16

The construction of a highly accurate GNSS guided weapon requires a great deal of value added components and subsystems, many of which are difficult to obtain in MTCR-controlled markets. Given US determination to jam GNSS in the time of war, including the commercial un-encrypted GPS signal, the only alternative a potential opponent has is to combine cruise missile/UAV GNSS guidance with less accurate inertial navigation systems. This does not mean, however, that the US can rest assured that the diffusion of cruise missile/UAV subsystem technologies to lesser-developed countries will not occur, only that it will be slow enough for military planners to devise and implement protection strategies to counter them.

Dominating the Market: The Seizing the Commanding Heights

Where there is significant international economic competition leading to technology transfers, and it is difficult if not impossible to stem the spread of sensitive technology, the counter-intuitive argument is that the United States may need to export more potentially dual-use technology in order to insure that it can maintain at least some influence on the proliferation. By "dominating the market" for particular technologies, the US would have 1) leverage over not only specialized physical assets, but also the economic "motivation" needed to produce the certain technologies indigenously in any large quantities and 2) would have information that the market might not have about the technology, manifest in tacit knowledge acquired in the technologies development. Given the commercial benefits of telematics, and global competition in services, a dominate-the-market solution appears to be the most viable long-term strategy.

By leveraging its massive base of GPS users and application providers, and designing and implementing advanced augmentations that will attract more users to the system, the US can potentially raise the commercial barriers to entry for Galileo and GLONASS enabled applications. In the case of telmatics, dominating the market at particular chokepoints, holding predominance in key guidance technologies and vital navigation services and networks, substitute to a degree the loss of strategic control of GPS. As Berkowitz argues, "…countries that want command of the nets must be willing to sell computers, software, and communications services. Otherwise they will lose the leverage that the seller gains."

The ability of adversaries to draw military utility from a technology is key, not simply whether they can obtain the technology in the open market. It must be kept in mind that proliferation is irrelevant if it leads to only a negligible improvement in an opponent's forces.[91] Ironically, part of the way the US can reduce utility of systems to adversaries is by making some key technologies commercially available. For example, the Argentines in the Falklands War did not understand that bombs they had purchased from Great Britain before the war were designed not to explode if dropped at altitudes of less than 200 feet. The British understood this limitation and tailored their tactics accordingly, forcing the Argentines to fly low.[92] Information asymmetries of this type can exist between the producer and user of any given technology, and this kind of information advantage is more likely to come about if the US is willing, in the face of international commercial competition, to let select technologies diffuse. By dominating the global market, the US may lock out other third party technologies that might be equally dangerous, but provide the US with much less leverage in a wartime contingency. In this sense, by making it harder to penetrate foreign economies and capture market share, some export controls may actually make it harder to win the information "battles" taking place inside the larger war.[93]

In the near term, potential adversaries will likely encounter great difficulties in integrating various components into a viable system, and given export controls, will have difficulties producing such weapons in any significant quantity. There is a substantial local knowledge in the development of such sophisticated systems, which can include complex interfaces between of avionics and flight subsystems: terminal sensors, terrain-aided navigation systems, GPS and INS guidance packs, payload, flight control and propulsion systems. This kind of knowledge cannot be condensed to programmer's code or systems schematics; but rather must be acquired by direct learning and experience with the technology.[94] The US should closely monitor non-MTCR signatories for exports of sophisticated guidance system technology and other important aircraft and missile subsystems. Such near term efforts by countries to import components and to build

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[91] Derek W. Smith, "Double Edged Sword, Controlling the Proliferation of Dual-Use Satellite Systems," *National Security Studies Quarterly*, Volume VII, Issue 2 (Spring 2001). p 33

[92] Bruce Berkowitz*, The New Face of War: How War Will Be Fought in the 21st Century* (New York : Free Press, 2003), p 27.

[93] IBID, p. 196

[94] Ann R. Markusen and Sean S. Costigan ed., *Arming the future : a defense industry for the 21st century*, , (New York : Council on Foreign Relations Press, 1999.) p.400

and test GNSS enabled cruise missiles/UAVs will likely take time and would be visible to intelligence monitors, providing the US with time to develop specific contingency plans and countermeasures.

Furthermore, absent a political agreement between the three major GNSS operators, the US will likely need to rely on a diversified portfolio of measures to counter the increasing availability of GPS guidance for cruise missiles/UAVs. In the near term, however, the US can come to an agreement with the EU and Russia on a clear separation of frequencies. This should allow the US to focus its NAVWAR strategy to disrupt these systems in the event of war. As telematic services become more differentiated and commercial markets appear for more robust features such as signal augmentation for urban areas, free GNSS services might slowly diminish in importance as encryption and authentication may be implemented to prevent users from free riding onto value added services. Eventually GNSS services may split into two categories. The first category will include encrypted subscription channels that provide exceptional quality of service for civilians and military alike. The second category will be public signals that are dithered to reduce their military utility, analogous to the US “selective availability” policy for GPS that President Clinton ended in May of 1999. In the distant future, it is not inconceivable that proliferation of GNSS guidance packages might be checked by greater demands for such built-in controlled access features from both military and commercial users.

Balancing Political Cooperation and Commercial Competition: Lessons from Galileo

The dispute over Galileo demonstrates that counter-proliferation efforts really depend on not just a “dominate the market” strategy and concomitant defense contingency planning, but also on significant international cooperation in the efforts to make the global flows of advance technologies more transparent. The MTCR, and the Wesslar agreement are two such agreements, but both of these coalitions require significant time and energy to maintain in the face of growing economic competition in telematics applications and services.

The row with the Europe over Galileo was avoidable, but unfortunately could not be separated from the widening political rift between the US and Europe. For the longest time most

EU countries had agreed with the US contention that a second GNSS network would be needlessly redundant and too expensive to launch and maintain. Galileo, however, was being pushed in the context of the expanding divide between the US and Europe over defense. Stirred to action by the invocation of Article 5 of the North Atlantic Treaty, Europe began to feel its growing irrelevance after the United States refused NATO offers for help after September 11th. Deputy Secretary of Defense Wolfowitz briefed the Europeans on Washington's independent plans for a "wide-ranging, long-term approach the U.S. is adopting to combat terrorism." There was no mention of a military role for NATO, and in light of the often-fractious NATO military efforts in Yugoslavia in the 1990s, Bush Pentagon officials had hinted that they did not want to fight what some derisively referred to as "war by committee."[95] The debate on Galileo became part of this larger rift after European NATO defense ministers received a purportedly “angry” letter from the same deputy secretary, decrying the threat Galileo posed to vital GPS frequencies, and urging NATO defense ministers to use their influence to convince their respective governments not to support funding for Galileo.

The US had missed a golden opportunity to lock Europe into GPS because it had poisoned an already spoiled atmosphere by overplaying its hand in NATO. Since European aspirations in dual use space technologies seemed relatively easy to dislocate in the past, and given preeminence of GPS, the US “take it or leave it strategy” in the early negotiations with EU over EGNOS and Galileo seemed the most obvious track. Contentious behavior is, however, *self-liquidating* over time, the victim of both failure and success. If it fails resistance is then overestimated. If it succeeds and the other yields, then resistance to the yielding is likely to grow later and the party will be force later to abandon the tactic. [96] But given the current climate, rough methods resulted in more European resistance, instead of more yielding. Overly zealous lobbying designed to demonstrate to the EU the futility of moving forward with Galileo, had in fact alienated some EU members who favored GPS over Galileo, but were frustrated by the lack of a level playing field in the negotiations.

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[95] “How the Iraq Confrontation Divided the Western Alliance,” *Wall Street Journal*, Marc Champion, Charles Fleming, Ian Johnson And Carla Anne Robbins, March 27, 2003
[96] J.Z. Rubin, D.G. Pruitt, S.H. Kim, *Social conflict: Escalation, Stalemate, and Settlement*, 2nd Edition p. 43

By not sharing US technological resources, the US provides friends an foes alike with the incentive to try to match them.[97] Motivation can make a difference, given that in the past militarily significant technologies are often developed almost simultaneously in different nations. Given the often rapid spread, who can best use new technology as an instrument of war often depends on resources available in the economy, both domestic and global. But it also greatly depends on motivation to construct militarily useful applications.[98] By raising the costs of competition, or providing opponents with alternative goals, the US can use its market power to decrease window's of opportunity for proliferation.

[97] Joseph Nye and William Owens, "America's information edge" *Foreign Affairs*, March/April 1996 p25
[98] Thomas C. Hone and Norman Friedman, "Harnessing New Techologies" in *Transforming America's Military* ed. Hans Binnendijk (Washington D.C. National Defense University 2002) p. 33 Radar, for example, was under development as a military technology in eight countries (France, the Netherlands, Italy, the United Kingdom, Germany, the United States, the Soviet Union and Japan) before WWII.

CONCLUSION

A basic ”information warfare” strategy is that it is always better to settle on some measure of control over a potential adversary’s information systems, than to gamble on achieving total control and getting none. In promoting US technology in telematics, the US can exploit asymmetries in information that naturally exist between the producers and users of any given innovation. The sustainable match between the benefits of telematics and the costs of dual use technology proliferation is dependent on the US striking a complex balance between preventing diffusion of some technologies, allowing the proliferation of others, while at the same time hedging risks to forces by standing up effective countermeasure protection.

In a commercial idiom, Teece argues that nations and firms can move to protect their interests in ensuring that *domestic*, rather than *foreign* co-specialized assets capture the lion’s share of the externalities spilling over to complementary assets. This is done by the supporting infrastructure for those complementary assets by not allowing them to decay. A firm or a country whose strategic position is dependent on control of the commanding heights of the information age -- the networks, and the sensing and computing power on its fringes -- must build infrastructure that it is willing to share with others, lest it attract competition. The US should compete vigorously in commercial markets for telematic services related to GPS, but it also must ensure that the system does not decay, lowering its attractiveness to commercial users.

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APPENDIX 1

Some Civil Applications of GPS

Air Navigation	Nonprecision approach and landing Domestic en route Oceanic en route Terminal Remote areas Helicopter operations Aircraft altitude Collision avoidance Air traffic control
Land Navigation	Vehicle monitoring Schedule improvement Minimal routing Law enforcement
Marine Navigation	Oceanic Coastal Harbor/approach Inland waterways
Static Positioning and Timing	Offshore resource exploration Hydrographic surveying Aids to navigation Time transfer Land surveying Geographical information systems
Space	Launch In-flight/orbit Reentry/landing Attitude measurement
Search and Rescue	Position reporting and monitoring Rendezvous Coordinated search Collision avoidance

Source: Parkinson, 25