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ESD.85 - Integrating Doctoral Seminar on Emerging Technologies

Making the Leap – Opportunities and Risks of Emerging Technologies

Introduction

Much of the seminar has dealt with the uncertainties regarding the opportunities and risks of emerging technologies. The readings, lectures, and student case presentations have shown individuals and organizations at crossroads – deciding on a major investment, a project cancellation, or a technology adoption. Often they must make these decisions with limited knowledge, without the benefit of today's hindsight. This seminar has addressed several pre-defined cross-cutting themes that deal with the dilemma of making critical decisions under great uncertainty. Instead of directly addressing one of those themes, this paper attempts to address a "mega" cross-cutting question: **What influences decision-making on emerging technologies, given the uncertainties in the opportunities and risks?** Four factors have repeatedly appeared in the seminar readings and presentations: (1) the type of risk, (2) organizational and political context, (3) stage of technology development, and (4) past experiences.

Type of risk

People's acceptance of risk and readiness to move forward with an emerging technology depend on the extent to which the technology is applied to a life-threatening situation. The seminar presentations demonstrate that people and organizations are more willing to take greater risks – increases in both the probability and severity of the problem – when human lives or national security are at stake. With function-enhancing technologies, people are less likely to trade off other attributes, such as their health, safety, financial well-being, etc. in exchange for the possible benefits of those technologies. The Global Position System (GPS), ARPANET, supersonic transport, and unmanned aerial vehicles were all originally developed for military use, but have since spread to the civilian sector. These technologies were very costly and risky to initiate, but the motivation to protect national security was substantial enough to overcome these concerns.

Interestingly, once the technologies were considered for civilian use, the judgments about the risk-benefit balance changed. GPS was used to help the military locate themselves in potentially life-or-death situations, such as in the featureless deserts of Iraq during the 1992 Persian Gulf War. However, the Federal Aviation Administration (FAA) has been very reticent to rely on GPS for civil aviation navigation, where even one casualty associated with GPS malfunctioning might prove disastrous to the new application (Ho, Mozdzanowska et al. 2005). Supersonic transport had originally been applied to military jets. At first, when the technology transferred to the civilian sector, it appeared to move towards commercial viability, poised to replace jet aircraft. However, safety concerns highlighted by the July 2000 crash of a Concorde, ultimately led to the grounding of all Concordes and discontinuation of the whole program. The public was not willing to accept fatal accidents at the price of faster, more technologically advanced aircraft when existing passenger air travel was considered very safe (Downes, Lewis et al. 2005).

Military and civilian applications are not the only situations where the difference in risk acceptance between life-threatening and function-enhancing situations is apparent. In medicine, patients' willingness to accept negative side effects increases with the efficacy of the drug and the seriousness of their condition. Former Aventis Chief Technology Officer, Dr. Frank Douglas, emphasized the substantial difference in attitudes towards drugs that treat life-threatening ailments and those that do not. The antihistamine Seldane treated allergy symptoms, a non-life-threatening ailment, so even a few deaths annually from drug interactions out of the millions taking the drug was unacceptable. As a counterexample, men dying from prostate cancer may be willing to tolerate very painful side effects just to live a month longer. Emerging technologies appear more attractive when the alternative options carry substantial risk of death or injury.

Organizational and political context

<u>Organizational culture</u>

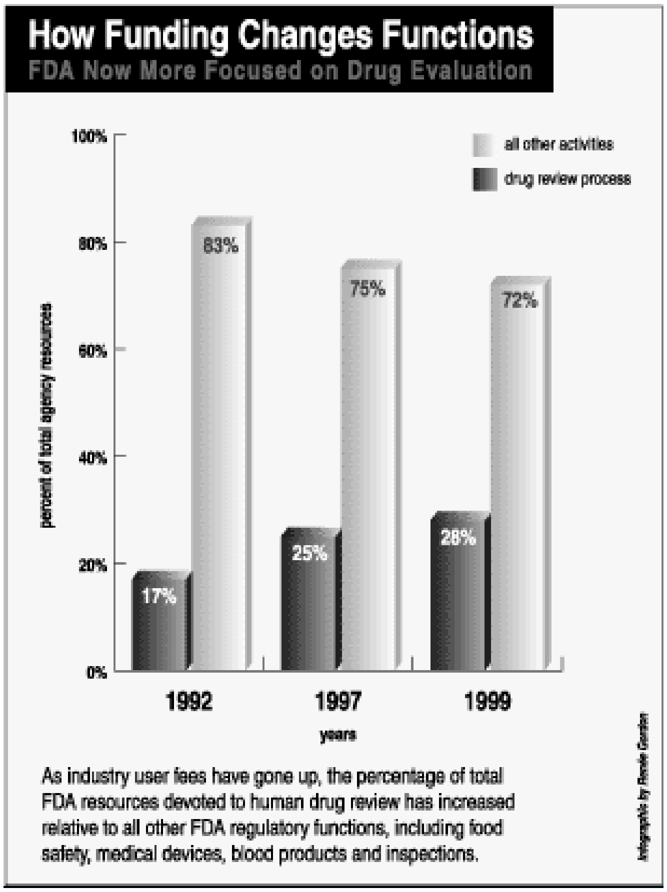
Those making the decision about emerging technologies are heavily influenced by organizational culture. In most of the presentations made during the seminar, there was a least one major organization involved in pivotal decisions. Many organizations were very risk averse, creating a barrier to pursuing opportunities with the often risky emerging technologies. The GPS case provides a clear contrast between the FAA and the Department of Defense (DoD). The DoD originally developed GPS, now known as NAVSTAR, exclusively for military use, without consideration of civilian applications. In the 1980s, its first function was to detect nuclear detonation. However, after the Soviet downing of a Korean passenger jetliner, the US and the rest of the world saw the value of GPS for civilian applications such as aircraft safety. Even before 1983, the DoD had been trying to interest the FAA in NAVSTAR, hoping that FAA would also share in the maintenance costs. FAA was highly skeptical of the accuracy and reliability of GPS. Even when DoD improved accuracy from 500m to 100m in hopes of reversing the FAA's opposition, FAA still resisted GPS technology. At best, GPS would be a back-up to existing ground-based systems, which the FAA perceived as more reliable. Moreover, FAA did not want to pay the user fees that DoD was requesting.

FAA's lack of interest can also be partially attributed to its risk-averse culture, especially compared to the DoD. As a military organization, DoD had a mindset that is more accepting of risks because military missions are inherently riskier. Meanwhile, the public perception of passenger flight was that it was very safe, safer than automobile travel. FAA did not want to adopt a new technology that would change that perception. The ground-based radar system had worked relatively well, so it did not see the value in trying something new. In recent years, the removal of selective availability and the use of the Wide Area Augmentation System (WAAS), a system of satellites and ground-based stations, have improved accuracy to below 3 meters. However, FAA has still not approved use of WAAS for civilian aircraft (Ho, Mozdzanowska et al. 2005).

Figure removed for copyright reasons.
GPS / WAAS diagram from Garmin Ltd. http://www.garmin.com/aboutGPS/waas.html

The FAA's response to UAVs (unmanned aerial vehicles) echoed its early reactions to GPS. Like GPS, UAVs were originally developed by the military. There were typically used in long-duration, high-risk surveillance missions (e.g. spy missions in enemy territory). Non-military UAV operation requires joint approval by the DoD and FAA, a cumbersome process that has limited UAV use. Access 5, a multi-agency collaboration, was designed to improve the process for integrating UAVs safely into the national air space. However, funding for Access 5 was recently canceled, which was partly attributable to organizational difficulties. FAA's conservatism made it reluctant to take on the risk associated with facilitating the increase of UAV use. It feared that UAVs would jeopardize the safety of manned aircraft. Ho and Hung (2005) concluded in their presentation that FAA was prone to Type II errors, such that they would rather reject something safe than approve something unsafe. Their mission is "to provide the safest, most efficient aerospace system in the world" and their vision is "to improve the safety and efficiency of aviation, while being responsive to our customers and accountable to the public." If a UAV were to fatally interfere with a passenger flight and it would not have been in the air without FAA's new streamlined approval, the FAA would likely bear the blame, even if Access 5 were a collaborative effort (Ho and Hung 2005).

Historically, the Food and Drug Administration has also been known for its risk-averse culture. Responsible for ensuring the safety, efficacy, and security of drugs, the FDA holds the power to approve drugs, and to withdraw approvals if the drug is found to be unsafe or ineffective. In the past decade, the FDA has been subject to increasing criticism about the loosening of its safety culture, and its close ties to the drug industry. In 1992, Congress passed the Prescription Drug User Fee Act, allowing FDA to collect user fees from drug companies seeking approval for marketing drugs. It was designed to speed the notoriously slow drug approval process. The funding has allowed the FDA to higher more review staff and to update its information systems. Although the program did not change the FDA’s review standards, it did accelerate the drug approval process and increased the percentage of the agency’s resources devoted to drug review (Thompson 2000).



Source: Thompson, L. "User Fees for Faster Drug Reviews." *FDA Consumer Magazine*, 2000.

Critics claim that the FDA’s greater attention to drug approval left it less equipped to conduct post-market surveillance of drug safety. In 1997, Seldane was withdrawn from the market by its manufacturer because of the risk of fatal heart arrhythmia associated with drug interactions. Some speculated that the delay in withdrawal was caused by FDA’s decreased attentiveness to safety issues.

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FDA’s dual role of approving drugs and monitoring drug safety puts it in a precarious position. A “safety culture” may not fit well if the FDA is under intense pressure from industry and public to accelerate drug approval. Some have suggested separating the drug review function from the FDA and placing it under the authority of an independent review board. This is exactly what has been done in 2005. A new 15-member Drug Safety Oversight Board was recently created to oversee the FDA’s drug safety program. However, it is still criticized because 11 of the 15 members are former managers of the FDA's Center for Drug Evaluation and Research, which is responsible for drug review and approval (Kaufman 2005). Even if these 11 board members are capable of evaluating safety issues objectively, their past affiliations open the door for criticism. Medical experts without FDA or industry ties would seem to be more credible choices for this oversight board.

Organizational culture plays a major role in the decisions made by private organizations as well. In the 1970s, AT&T had the opportunity to take over ARPANET, which later evolved to what is now known as the Internet. At that time, AT&T had the monopoly on the telephone network, which predisposed them to staying with their existing business model. There was no incentive to adopt an emerging technology to compete with rival companies. AT&T had built an infrastructure around circuit switching. Adopting packet switching would require new infrastructure, financial plans, and standards. It could threaten to cannibalize their circuit switching model. At the time, AT&T did not see how to make money from the new data sharing network. Given the subsequent Internet boom, AT&T clearly made the wrong decision. It is easy to criticize AT&T as a sleeping giant, who did not notice its smaller, more agile competitors and emerging trends (Hung and Lewis 2005). AT&T’s behavior is consistant with innovation expert Clay Christensen’s characterization of shortcomings in large companies’ ability to innovate. Seeking to strengthen their existing lines of business, large companies tend to develop incremental, sustaining technologies rather than disruptive technologies. It is usually the smaller organizations, often with an adventurous, start-up mentality, that will develop disruptive technologies, which lead to major shifts in business models and customer demands (Christensen 1997).

DEC, the company that introduced the first minicomputer, a truly disruptive technology, exemplified a “culture of innovation.” Even though it grew quickly in the 1960s, DEC retained the small company feel that Christensen claims is crucial to fostering disruptive technologies. Individuals and small design groups were given significant autonomy and responsibility (Falkenthal and Downes 2005). This distributed management style spilled over to the customers. DEC wanted its users to interact with the technology, and encouraged hobbyists to make improvements, which could then be integrated into the next generation of the technology. Despite DEC’s early success, their growth into large, cumbersome corporation may have led to its inability to adapt to the changing economic and technological climate. DEC failed to foresee the dominance of personal computers in the home and business markets. Its identity as a “full solutions” company was threatened by the entry of “category killers,” innovative companies that individually developed expertise in a narrow set of functions but collectively covered the entire solution space (Falkenthal and Downes 2005).

Although the culture in various organizations is unique, large government agencies and large companies seem to share a conservative outlook towards emerging technologies. Large government agencies, like the FAA and FDA, may fear the repercussions associated with public accountability if the risks are greater than expected. Large, stable companies may fear losing their foothold in the market if their technology bets are wrong. Staying with the status quo often seems to be safe, but historical cases demonstrate how organizations can miss major opportunities.

National competitiveness

The previous section discussed how organizational culture can inhibit or facilitate the development and adoption of emerging technologies. In cases where the technology is relevant to national security or national competitiveness, political leaders may give the technology additional support or steer development in a politically amendable direction. Decisions may not be technologically or economically justified, but motivated by the national interest. On the positive side, this may lead to support of promising technologies that would not be otherwise funded by slow government bureaucracies. Unfortunately, it can also lead to excesses in public spending, unchecked by objective analysis.

As mentioned before, several of the technologies covered in this seminar - GPS, Arpanet, SST, and UAVs – were motivated by military needs, so they did not require the same level of economic justification had the technologies been developed in the private sector. Instead of discussing the national security justifications for these technologies, many of which may be classified and therefore obscured from public view, this section focuses on the national competitiveness driver.

While the US was initially driven to invest in GPS for military use during the Cold War, the Europeans' decision to deploy their own system, Galileo, is motivated by the desire for regional competitiveness and independence from the US. At first glance, it does not make sense for Europe to spend hundreds of millions of euros on a new system if GPS is free and already established. Selective availability no longer restricts the accuracy of the GPS signal to civilians worldwide and the US has promised to keep GPS operational indefinitely. Nevertheless, Europe wants to have its own system. GPS is still controlled by the US military, and the Russian system, GLONASS, is underfunded and incomplete. Europe fears that in the event of a war, the US may decide to shut off portions of the system, disrupting civilian use of the system, which has skyrocketed since the early 1990s. Galileo will be used for both civilian and military purposes, but supposedly will not be shut off for military purposes. Europe first decided to develop Galileo in 1998, but the project seemed doomed for failure because of lack of funding and strong US opposition to a competing GPS network, especially after the September 11, 2001, terrorist attacks (Ho, Mozdzanowska et al. 2005).

The strong US opposition to Galileo actually had the opposite of the desired effect – it actually strengthened the European Union's resolve to have its own independent system. Galileo boasted better quality and accuracy than the US system. The project ultimately received more than enough funding. Even China joined the Galileo project in September 2003, contributing US$300 million to the cooperative effort. Many countries saw involvement in Galileo as a way to help their domestic companies gain entry into a market largely dominated by American firms. Pursuing the Galileo project despite American opposition also reflected the international community's resentment of US actions on other fronts. America's determination to begin military operations in Iraq in March 2003, without the backing of most of Europe and the United Nations, and its refusal to partake in the Kyoto Protocol embodied America's maverick, go-italone attitude toward international affairs. In this context, Europe and other countries were probably skeptical of US promises to keep GPS fully functional for the rest of the world. Moreover, the free US system could not be held responsible if service degraded or discontinued. The Galileo system offered free and paid services. The premium paid service would be regulated and guaranteed, subject to recourse or liability in the event of service disruption. Recognizing that Galileo was proceeding forward regardless of US opposition, the US signed a 2004 agreement such that there would be no interference between the existing GPS and upcoming Galileo system (Ho, Mozdzanowska et al. 2005).

Supersonic transport (SST) was another military-initiated program driven by national competitiveness concerns. By the 1950s, it had been demonstrated that supersonic military jets were feasible, and SST seemed poised to overtake commercial jet aircraft as the dominant commercial flight technology. The Soviet Union, UK/France, and US each funded domestic SST programs in the 1960s to compete for trade balance, technological superiority, and national prestige (Downes, Lewis et al. 2005). From a global perspective, it would have been more cost-effective for one country to develop the technology and then sell it to the other countries' airlines, or for a single international consortium to develop the technology together. However, the pursuit of SST turned into a race - each country wanted its domestic firms to gain the technology capabilities to become SST technology leaders. If not for these strategic considerations, investment in SST would have been difficult to justify from an economic standpoint. For example, the Soviet government heavily subsidized the development of Tu-144S, the world's first supersonic aircraft. Aeroflot, the Soviet airline, began using the Tu-144S for freight and mail service in 1975. It flew for less than year of passenger service before a fatal accident in 1978 returned it to mail-only flights. A key reason for France's development of SST was its resentment of US dominance in aircraft technology. The British and French governments funded the Concorde as a way to compete with the US-dominated aircraft production market (Downes, Lewis et al. 2005). The British and French governments sought to grow the competencies of their domestic companies and to retain the expertise of their technology professionals on European soil, rather than losing them to American firms. The development of related technologies would also have spillover benefits to other domestic industries. The British-French cooperative effort ultimately led to the Airbus consortium, which established itself as a rival in passenger jet production to US-based Boeing. As in the GPS case, there was a desire to challenge the existing US dominance in this technology area.

Stage of development and key players

The opportunities and risks considered, and the subsequent actions taken may depend on the emerging technology's stage of development. Hung and Lewis (2005), in their presentation on packet switching, posed the question: "When is the best time to both consider and implement technical refinements to better address societal concerns? Who best to do this?" Missteps and unforeseen outcomes in our retrospective emerging technology cases imply that decision-makers or others with influence on technology pathways should think about implications as early as the pre-development stage. If insurmountable social and economic barriers were identified early on, the parties involved could avoid expensive and time-consuming technology investment. However, the literature cited by Hung and Lewis (2005) indicates that people do not focus on the social and economic implications until the basic technology is shown to be functional. The rationale may be that it is not worth worrying about the implications until the technology is actually feasible.

The individuals closest to the technology, i.e. scientists and engineers in R&D, may be biased to overselling the upside of the emerging technology. They might assume that society will eventually solve the economic and social concerns through regulation or market-based measures. These technologists have the incentive to emphasize their technology's benefits in order to secure additional funding for research; it would not be in their interest to point out risks that might jeopardize the still-nascent technology.

However, once the technology is functional and well-developed, those same scientists and engineers may be in the best position to identify the flaws in their own design. Technology promotion may then shift away from the technologists to managers and salespeople. This is not counter to the technologists' initial enthusiasm because their ultimate goal is for the technology to function to its full potential. Pointing out problems would be the first step in improving the technology. Prior to the space shuttle Challenger's final flight, the different thought processes of engineers and managers became very apparent. Engineers at the solid rocket motor contractor Morton-Thiokol were concerned about the effect of cold temperatures on the rubber O-rings and recommended a launch delay. Meanwhile, managers had to make "GO/NO-GO" decisions; their cost and schedule pressures competed with the engineers' safety concerns. Convinced that safety risks were insignificant, managers tended to focus on results that supported their decision to proceed with the launch. In engineering discussions about delaying the Challenger launch, a senior vice-president at Thiokol pushed for the launch despite the reluctance of the engineers. He actually told the technically trained managers: "Take off your engineering hat and put on your management hat" (CAIB 2003). By suppressing the engineers' natural skepticism, he was trivializing their input and downplaying the risks.

Dr. Frank Douglas highlighted the tension between the marketing department and the R&D department at any pharmaceutical company. The marketing people are eager to discover and promote new uses of a drug to increase sales. The additional costs are relatively small compared to developing a new drug, and the payoffs could be enormous. However, the R&D people are more cautious. They fear that the risks of new applications, such as increasing dosage to treat other ailments, may uncover dangerous side effects from a drug previously thought to be safe. This could threaten the reputation and sales of the drug for its original purpose. The R&D staff seek more time for testing, not a dissimilar response from the Challenger shuttle engineers' desire for good data correlating cold temperatures and O-ring resilence (CAIB 2003). In both these cases, the scientists and engineers were in a good position to identify potential risks, especially after they had the opportunity to collect data on the technology in actual use. As members of a technology organization, they do have the credibility to critique the technology that they developed, but may not have the incentive to do so if their comments hurt their reputation or fall on management's deaf ears.

It is not always the case that social and economic implications are ignored until the technology is developed and proven. In some cases, when the technology is similar to past technologies or falls into a well-established category of technologies, there may already be built-in requirements or criteria for acceptable risks. In drugs and passenger aviation, there are existing technologies that have established standards, which can be applied to the new technologies. This does require a certain level of familiarity, a concept introduced in Dr. Frank

Field's presentation to the seminar. The new technology has to be likened to something else that is well understood (Field 2005). Seldane, which was considered a breakthrough antihistamine, still belonged to the broad category of drugs, which had a regulatory framework created by the FDA. Supersonic transport could be compared to existing passenger jet aircraft. For drugs, there are requirements for efficacy and safety, which explains the long process of laboratory studies and clinical trials. A system of post-market surveillance of drug safety already existed by the time problems with Seldane emerged. Therefore, drug companies have long been aware of the consequences of discovering drugs to be unsafe after drug approval. Passenger aircraft is an obvious "familiar" predecessor to SST. People had already experienced passenger jet flight, and were aware of issues of speed, noise, emissions, fuel consumption, and cost. Although SST behaved differently than subsonic aircraft, supersonic aircraft could still be measured against these metrics. The public expected SST to be as safe as regular passenger air travel. Because of the ability to compare the two, SST's status as an emerging technology did not lower people's expectations of its non-speed related characteristics. For example, when the Boeing 747 was introduced, the government developed noise requirements for aircraft. It decided to apply the same requirements for both subsonic and supersonic aircraft (Downes, Lewis et al. 2005). SST was not to be given any special breaks simply because it was a new and exciting technology.

Seldane/Allegra and SST emerged within a well-developed framework for dealing with risk. Metrics already existed to evaluate their performance. However, there are plenty of technologies that have no clear ancestry in other technologies. One option is to take the "wait and see" approach that has dominated past decision-making about emerging technologies. Although there are some who draw attention to implications at the early stages, they are often seen as alarmists who are not taken seriously. There needs to be greater onus upon the developers of the new technology to investigate risks early on, even if it seems counter to their enthusiasm for the technology's success. They should view an analysis of possible risks as a way to preempt attacks on their technology and to design features to overcome possible social and economic barriers to the technology's deployment.

Learning from past experiences

Decisions made about emerging technologies are seldom set in stone. There are opportunities for adjustment once more information is gathered or outcomes are observed. While it is true that some outcomes are irreversible and future options may be constrained by past decisions, organizations can use lessons from past experiences for their next decisions. For instance, they may adopt risk management measures to mitigate undesired consequences or modify the technology to accommodate unexpected applications of the technology.

Round 1 of adjustments

When the FDA approved the non-drowsy antihistamine Seldane for sale in the US in 1985, Seldane's interaction with other drugs to cause potentially fatal heart arrhythmia was not known. However, once Seldane became widely available, patients and doctors reported adverse reactions in the early 1990. The FDA requested further investigation into drug interactions and mandated the provision of more information to prescribers and patients about the risks. Aware of the drug interactions but cognizant of the Seldane's benefit to allergy suffers, the FDA required the manufacturer, Hoechst Marion Roussel, to issue letters to doctors and added a "black box" warning to the drug label. The black box warning is the most serious warning that is required by the FDA.

In developing GPS, the US military had assumed that its use would be limited to the military. Only military-issued receivers would be able to obtain the encrypted signals. However, when civilian interest in GPS technology grew, civilians wanted to use GPS for emergency response, navigation, and other non-military applications. Seeking to accommodate this unexpected civilian demand, the US Defense Department's Joint Program Office (JPO) added more frequency bands for civilian uses. However, it was concerned about the national security threat if civilians, particularly those with nefarious intentions, had access to the same level of location accuracy as the military. Therefore, the JPO implemented selective availability to limit the signal accuracy for non-military users. The encrypted signal, accurate up to 10-20m, would only be available to the military, and the civilian signal would be degraded to 100m.

Round 2 of adjustments

In both the Seldane and GPS cases, the warning letters/labels and selective availability can be viewed as risk management strategies to reduce the downside risk of supposedly beneficial technologies. However, the strategies did not work as well as expected, so further responses were necessary. Despite the black box labels and "Dear Doctor" letters, some doctors and pharmacists were still giving patients contraindicated drugs (i.e. drugs that cause adverse side effects when taken together). The lack of updated drug interaction databases and centralized patient information contributed to this problem. According to Dr. Frank Douglas, Hoechst's interest in making Seldane an over-the-counter drug put it under further FDA scrutiny about its safety, especially if patients could purchase the medicine without consulting a physician or pharmacist, who was supposed to provide the last check against potentially fatal drug interactions. Continued concerns about Seldane and the availability of Allegra, a Seldane substitute without the adverse side effects, led the FDA to withdraw Seldane from the market.

Selective availability turned out to be a failed experiment by the JPO. Private companies and even government organizations, like the Coast Guard, FAA, and the Army, developed differential GPS (DGPS), using satellites and ground-based stations, to enhance accuracy up to 10 cm. During the 1992 Persian Gulf War, the military turned off selective availability on the non-encrypted frequencies. A shortage of military receivers prompted the purchase of commercial receivers, which could not access the encrypted military signal. The success of GPS use during the war fueled interest and investment in the technology. Decision-makers realized increased GPS accuracy improves civilian safety and services. Moreover, the development of DGPS showed that selective availability would not stop anyone from having a signal at least as accurate as that of the military. There was no longer any national security justification for the GPS signal degradation. On May 1, 2000, President Clinton officially turned off selective availability. While the military still keeps its own encrypted frequency bands, the accuracy of GPS is the same for the military and civilian sectors (Ho, Mozdzanowska et al. 2005).

The emergence of GPS gave rise to a host of other technologies not anticipated by the original developers of the technology. GPS was initially designed as a passive technology – the user would use it to geographically locate him/herself. With the recent integration of GPS in cell phones, GPS can be used to track users, beyond the 911 emergency response function for which the integration was intended. This creates privacy concerns that did not exist at the time GPS was invented. The civilian sector demand has a different set of criteria than the military sector, which led to the rise of Galileo. Companies seeking to manage transportation systems (e.g. aircraft) based on GPS are concerned about the lack of recourse if the free GPS is shut down or compromised. With its premium services, Galileo can provide the reliability and independence from the US military that some private businesses seek (Ho, Mozdzanowska et al. 2005).

The FAA and the DoD made decisions about the availability of Seldane and GPS prior to the technologies' widespread use. However, because of the discovery of Seldane's additional risks and GPS' wider applications, the agencies had to make mid-course corrections once the technology was in use. These decisions had to be revisited once they were shown to be ineffective, or alternative solutions (e.g. Allegra) were available. Organizations do not have to be immobilized with indecision if many uncertainties still exist at the time of decision-making. Granted, it is preferable to identify avoid the harmful and irreversible impacts upfront, but knowledge grows as a technology matures. It seems inevitable for changes to be made once the technology and its uses are better understood.

Most organizations have a reactive response to unexpected consequences from their new technology, but some may encourage user-led changes and incorporate those changes in the next-generation technology. DEC recognized the minicomputer as an evolving technology. Its minicomputer design encouraged user interaction and modification. Unlike some of the other technologies discussed in the seminar, making changes to the minicomputer did not require an entire laboratory facility or expensive equipment. Most early users were hobbyists who liked to tinker at home with their minicomputer. They provided "free labor" to DEC, as they worked out problems and made improvements to the design. DEC's openness to user interaction influenced the open source software trend in computer, where users voluntarily write and freely share software to a community of users. Improvements are then incorporated into the next version of the software.

Conclusion

The seminar revealed many examples of individuals and organizations which had to make pivotal decisions about emerging technologies amidst uncertainties about the risks and opportunities. The readings and presentations in the seminar indicate that this type of decision-making is influenced by a variety of factors. Life-threatening situations or technologies with life-or-death implications encourage designers and users to be more risk-taking with emerging technologies. Organizational and political context play an important role in public and private organizations. Military-related organizations tend to be more eager to invest and adopt new technologies, while conservative government agencies put up more resistance. Large, well-established companies have difficulty accommodating disruptive technologies, which may be the purview of smaller, more agile companies. Meanwhile, national competitiveness may motivate governments to pursue technologies that would not otherwise make sense from an economic standpoint. Social and economic considerations in decisions are often ignored until the technology is functional and proven, unless applicable frameworks or guidelines exist from preceding technologies. Even if technologists are biased in promoting their technology, they may be the most knowledgeable and committed to finding problems and improving future versions of the technology. The challenge is giving them the incentive and outlet to do so. Finally, mid-course corrections do occur; later decisions are informed by past experiences and new developments.

References

CAIB (2003). Columbia Accident Investigation Board Report Volume I. Columbia Accident Investigation Board. Washington, D.C., NASA.

Christensen, C. M. (1997). The Innovator's Dilemma. Cambridge, MA, Harvard Business School Press.

Downes, K., S. Lewis, et al. (2005). Supersonic Transport. ESD.85. Cambridge, MA.

Falkenthal, D. and K. Downes (2005). The Rise and Fall (and Rise?) of the Minicomputer: Engineering, Management, and Technological Change. ESD.85. Cambridge, MA.

Falkenthal, D. and C. Ng (2005). Seldane/Allegra Case Study. ESD.85. Cambridge, MA.

Field, F. (2005). Ubiquity, Personalization and Culture. ESD.85. Cambridge, MA.

Ho, A. and S. Hung (2005). Integrating UAVs into National Airspace (Safely). ESD.85. Cambridge, MA.

Ho, A., A. Mozdzanowska, et al. (2005). GPS Case. ESD.85. Cambridge, MA.

Hung, S. and S. Lewis (2005). The Evolution of Packet Switching as an Emergent Technology. ESD.85. Cambridge, MA.

Kaufman, M. (2005). Drug Safety Panel is Criticized. Washington Post. Washington, D.C.**:** A5.

Thompson, L. (2000). User Fees for Faster Drug Reviews. FDA Consumer Magazine.