

**TECHNOLOGY STANDARDS AND PERFORMANCE: THE  
IMPACT OF SOCIAL NETWORK SERVICE INTEGRATION AND  
OPEN TECHNOLOGY STANDARDS**

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by

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OPEN TECHNOLOGY STANDARDS**

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## SUMMARY

For at least hundreds of years, if not longer, industries have been regularly transformed by the adoption of standards. Early examples from the early nineteenth century include the standardization of railroad track gauges and the introduction of interchangeable parts in the production of munitions. With the advent of the modern technology era, the introduction of standards has continued to transform industries that are now information technology driven. However, despite the broad consequences the introduction of standards presents, there remains a limited understanding of them.

In this work we begin to build upon our understanding of the impact of standards by conducting a study on each of two distinct industries that have significant implications for society. The first industry considered is online services, focusing on an increasingly dominant subset that contains online communities. This industry is being transformed by the introduction of de facto standards for user profile management through social network service integration. The second industry studied is the defense avionics industry. This industry is positioned to potentially be transformed by the introduction of an open technology standard for software development.

In the first study we investigate the impact of an increasingly common but understudied design option available to online communities: whether to integrate with a social network platform such as Facebook or Google+. Social network platform integration may provide several benefits to an online community, including creating more social interaction opportunities for members and helping members share personal information with each other to facilitate the creation of social bonds. Theory suggests that

both of these factors (opportunities for interaction and disclosure of personal data) enhance the success of bond-based online communities, i.e., those in which member attachment to the community is driven by social bonds with other members. However, some elements of the theory have not been tested, and the theory does not consider the possibility that interaction opportunities and the disclosure of personal information might harm the online community by creating information privacy concerns among users. To address this gap, we tested the effect of implementing the “Login with Facebook” feature on new member registration and member social bond formation in an online virtual world community. Using a randomized field experiment as well as archival data analysis, we found that Facebook integration led to lower registration and lower social bond formation. I.e., it had a consistently negative effect on the online community. In addition to contributing to theory about the design of online communities, our results are also of practical interest to managers of online communities who have implemented or are planning to implement social network platform integration as well as to social network platforms who would like for their integration services to be more widely adopted.

In the second study we examine the impact of introducing an open technology standard to the U.S. Defense Avionics industry. U.S. Defense Avionics is a multi-billion dollar industry featuring a monopoly buyer and pseudo-monopoly sellers, and its interplay of regulation and competition have traditionally favored secrecy and proprietary design as companies vie for huge multi-year contracts in a feast or famine market. Recognizing this, the U.S. government launched an initiative to develop an open technology standard jointly with industry, with the intention of using these standards to leverage the anticipated competition and efficiency benefits. Using a combination of

interviews and a Delphi study, we examine the impact of this standard on software project effort across key industry firm archetypes. We find that experts anticipate a significant premium in the short term that transitions to cost reduction in the long term, with these expectations varying by firm type. This work contributes to the literature on open standards and learning by validating and quantifying the effect, and provides unique insights into U.S. Defense Avionics industry. This study also informs both expert and industry expectations as well as provides a best estimate of the actual impacts of adopting the standard.

## CHAPTER 1: INTRODUCTION

Industry firms must continuously make design decisions. A key part of that ongoing decision making process is deciding the extent to which they should embrace upcoming and existing standards. Just as technology continues to transform society, standards affecting technology have sweeping implications for both the producers and consumers of those products, goods and services. However, it is unclear whether or not those implications will be positive. From the firm's perspective, these technology standards hold the potential to expand market share and to create production efficiencies and economies, but they also could contribute to loss of market and introduce additional overhead into production. From the consumer's perspective, standards may lower costs but could also decrease variety.

Standards may be differentiated by their functional role. Technology standards, though not definitively so, typically refer to compatibility standards. While standards may be generically defined as "a construct that results from reasoned, collective choice and enables agreement on solutions to recurrent problems", compatibility standards are the properties a product must have to work with complementary products within a product or system (Tassey 2000). Several decades of research has established a number of possible benefits from the use of these standards, however, there remains limited empirical investigation into the specifics of those implications with research remaining largely conceptual (Katz and Shapiro 1994). One challenge to testing the existing theory is that the context is likely to strongly influence how those theoretical precepts manifest. Therefore, to assess the implications for the introduction of a standard it is necessary to

sufficiently define not only the type of standard being considered but the context to which it is being applied.

In this work, we attempt to begin addressing the empirical implications of the introduction of standards. The overarching research question of this dissertation is: *What is the impact of introducing a new technology standard?* We approach this question by exploring these implications in two distinct but vital contexts. Due to their differences, in each case the relevant contextual details must be established and a custom procedure created that is tailored to the setting. First, we examine this question in the context of an online community's adoption of a de facto standard for managing their user profile information. As an online community, performance is assessed primarily through those factors reflecting the health of an online community, including membership count and social behaviors. Second, we examine this question in the context of the U.S. defense avionics industry and the introduction of a de jure standard for software development. Since software development performance is assessed primarily through project effort, the impact of the standard is considered through its impact on project factors that are deterministic of effort.

In the second chapter we begin addressing our overarching research question by investigating the impact of an emerging de facto standard for online communities: Integration with a social network platform such as Facebook or Google+. In a similar vein to how Amazon Web Services has arisen as a de facto standard for cloud computing, Facebook's integration services have experienced widespread adoption so as to be the

default option for 3<sup>rd</sup> party account and profile management.<sup>1</sup> As a design option, integration can provide online community members with enhanced social interaction opportunities by creating interconnections between the online community and the social network. It can also enhance online community social interactions by leveraging rich personal profile information from the social network. Prior research suggests that increased social interaction opportunities and the availability of rich personal information would help to foster interpersonal relationships, thereby enhancing the success of bond-based online communities, i.e., those in which member attachment to the community is primarily driven by social bonds with other members (Ren et al. 2007). However, the theory does not address the possibility that these changes could raise privacy concerns amongst prospective and current members. We therefore examine and test the theory in the process of assessing the impact of adopting this de facto standard. Our findings are of interest to online communities who have or are considering integration as well as to social network platforms that seek to have their integration services more widely adopted.

We state the research question formally as: “Is social network platform integration valuable for a bond-based online community?” We study this by examining the impact of implementing the “Login with Facebook” feature on the bond-based online community that comprises a social virtual world. Guided by theory on online community performance, we examine the effect of “Login with Facebook” integration on new

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<sup>1</sup> See <http://www.attunity.com/blog/amazon-web-services-de-facto-standard-public-cloud> for a discussion of Amazon Web Services as de facto standard (Archived by WebCite® at <http://www.webcitation.org/6ZXHQAsve>)

member registration and the development of social bonds between members following their successful registration. The “Login with Facebook” feature establishes a two-way flow of information between the online community and the social network platform, allowing the online community to access member’s personal information from Facebook and to update information on Facebook on the user’s behalf. In addition to enhancing social bonds, this integration could also benefit the online community by enhancing personalization and by streamlining user account/profile management. However, it could also harm the online community by raising privacy concerns.

To assess the effect on new member registration, we conducted a randomized field experiment. In the experiment, half of all visitors to the virtual world community’s home page were given the option to register using their Facebook accounts, while half were not. The Facebook option reduced new member registration by approximately 11% ( $p < 0.01$ ), which is both statistically and economically significant. By conducting a randomized field experiment we were able to attribute causality and claim greater external validity than we have been able to had our results been generated in a laboratory. We also examined whether Facebook integration might have an indirect effect on member registration by generating additional referral traffic, e.g. those who registered with Facebook accounts might be more likely to post references to the virtual world on Facebook. This online word-of-mouth could generate additional traffic to the virtual world community, which might increase the overall volume of registration even if the registration percentage was reduced. Although there was some evidence of a modest increase in visitors coming from Facebook, the increase was insufficient to compensate for the reduction in registrations demonstrated by the experiment. Therefore, referral

traffic could not plausibly offset the negative direct effect of Facebook integration on new member registration.

To assess the effect of Facebook integration on the development of social bonds between members, we compared the “friending” behaviors of community members who registered with their Facebook accounts to those who did not. This is an important consideration, as even if Facebook integration results in fewer members overall, it might engender a member base with unusually strong social bonds, thereby rendering it a net benefit. We found that Facebook connected community members acquired approximately 32% ( $p < 0.01$ ) fewer friends in the virtual world than did non-Facebook connected members. This suggests that Facebook connected members had greater difficulty developing social bonds with others. While this analysis was not causal, we can conclude that Facebook connected community members form less attachment to the community than do members who are not Facebook connected.

Our findings run counter to theoretical predictions that enhanced social interaction opportunities and rich personal information will help bond-based online communities. In contrast, we actually find harm, at least when the interaction opportunities and rich personal information stem from social network platform integration. We believe that the negative effect stems largely from information privacy concerns; as a result, future theory construction efforts should explicitly consider this dimension. Also, despite the widespread (and growing) adoption of the “Login with Facebook” feature by online communities and other services across the Internet, we find that this feature is harmful to the online community that we study. We advise online communities and other services to

proceed with caution when offering this feature, as it may generate user backlash, particularly in environments where information privacy is important.

In the third chapter we continue to address our overarching research question by investigating the impact of the introduction of an open technology standard on the U.S. defense avionics industry. U.S. defense avionics is a multi-billion dollar industry whose performance has significant and multi-faceted social welfare implications manifesting in national security, economics, taxes, fringe industry interactions, and the emergence of new technologies. Military aircraft feature a high initial acquisition cost, as well as a high maintenance cost thanks to a service life that typically spans decades. Increasing the complexity and thereby the cost of an aircraft, both for acquisition and maintenance, is determined by that aircraft's software (Arena et al. 2008).

The high cost of defense avionics software is generally ascribed to proprietary software development practices. Software solutions are built custom with limited regard for their ability to be updated or their use in alternate platforms, meaning that software solutions are often recreated with minimal reuse of code between systems and for upgrades of existing systems. Given mounting budget pressure, the U.S. military worked with a standard-setting organization (SSO) and formed an industry consortium with the goal of collaboratively developing an open technology standard for defense avionics software. A key goal of the consortium for the open technology standard is to foster the creation of reusable and extensible software artifacts in place of the custom developed point solutions that have been common. Other goals include increased asset value and decreased per function price, e.g. through increased competition and increased project efficiencies.

Decades of work exist on the potential influences of standards, however, there is little empirical work validating or quantifying these expectations. In contrast, most work is conceptual. In this chapter we begin contributing to our understanding of standards by building some empirical validation of our theoretical expectations. In considering an industry, we ask the following research question: *What is the impact of the adoption of a consortium-derived open technology standard on software development project effort?*

The U.S. defense avionics industry is a sizable and distinctive entity. Therefore, we should anticipate the presence of contextual factors that cannot be adequately controlled for that will strongly influence the impact of the introduction of the open standard (Joglekar et al. 2015). Indeed, there is increasing recognition of the need for deeply evaluating a given context in isolation if the context itself is sufficiently distinctive and important. The U.S. defense industry is both.

At the time of this writing the defense avionics industry was in the preliminary stages of contracting projects using the open technology standard. Given that defense avionics projects have a multi-year life cycle, and that adoption of the standard for projects will take some time to ramp up, it is likely that sufficient actual project data for empirical investigation will not be available for many years. Unfortunately, that means that by the time data is available on the performance of the standard the standard will likely be either well established or abandoned. And, even then, it is possible that protectionist policies may preclude researchers from examining this data. To address these challenges, we use the Delphi method to forecast the impact of the open technology standard by building a consensus estimate of this impact by a representative set of industry experts (Okoli and Pawlowski 2004). This is valuable in two ways. First, it

provides insight into the perspective of industry firms as to the impact. This perspective will shape the decisions being made to address the change the use of the open technology standard represents. Second, it provides the best available estimate of the true impact of the open technology standard.

This chapter contributes to the information systems literature in two fundamental ways. First, it provides empirical validation and quantification for prior theory on the implications of standards use and the nature of learning curves that is largely conceptual (Fong Boh et al. 2007; Todnem By 2005). Second, it provides a method for forecasting the impact of technology changes on firms by leveraging expert judgment and models of firm subgroup performance. Both contributions have significant implications for theory building. Pairing expectations with empirics allows the theory to be meaningfully and usefully vetted and refined as appropriate. The availability of a method for evaluating the impact of technology changes provides a useful lens for exploring a range of technology changes relative to expectations and approximations of reality (von Alan et al. 2004). In addition, these contributions have strong practical implications as well. By qualifying theory with estimates we are able to provide better guidance to industry. In addition, the method used is accessible to practitioners and empowers industry firms to evaluate changes proactively to better prepare for them.

Overall, this dissertation contributes to our understanding of standards by evaluating the impact of a standard in two contexts that are each highly distinct and consequential in their own right. The unique aspects of each required the development of a custom method for evaluating their performance, which in turn provides the second major contribution of this dissertation: the provision of methods for evaluating

performance in two different important contexts. In terms of theory, both research chapters provide tests of and suggest refinements for existing theory. In terms of practice, both research chapters suggest potential implications for choices firms are making and further suggest ways that firms can evaluate outcomes for themselves.

## **CHAPTER 2: THE VALUE OF SOCIAL NETWORK PLATFORM INTEGRATION FOR A BOND-BASED ONLINE COMMUNITY**

### **Introduction**

Researchers in Information Systems and related fields have made significant advancements in understanding online communities. This includes research on why people join and contribute to online communities (e.g., Butler 2001; Lakhani and Von Hippel 2003), how communities are organized and governed (e.g., O'Mahony and Ferraro 2007), and the social and economic value created by these communities (e.g., Armstrong and Hagel 2000; Boudreau and Lakhani 2013). From this research, a theoretical understanding of how to design online communities to optimize their success is emerging. For example, because we know that assuring members of the value of their contributions is important for encouraging knowledge sharing in online communities (Wasko and Faraj 2005), it follows that communities that are designed to provide this assurance are likely to be more successful than those that are not. We seek to contribute to this literature by investigating the impact of an increasingly common but understudied design option available to online communities: whether to integrate with a social network platform such as Facebook or Google+. This design option can provide online community members with enhanced social interaction opportunities by helping them involve their social network “friends” in the community. It can also make the rich personal information from users’ social network profiles (including demographics, interests, and social graphs) available to members in the community.

Studying this is important both theoretically and practically. From a theoretical standpoint, prior research has theorized about how increased social interaction opportunities and the availability of rich personal information – both of which are supported by social network platform integration – will influence the success of online communities. For example, Ren, Kraut, and Kiesler (2007) combined the research on online communities with theory from social psychology to propose a set of design recommendations for online communities. They theorized that increased interaction opportunities and the availability of rich personal data would help foster interpersonal relationships, thereby enhancing the success of bond-based online communities, i.e., those in which member attachment to the community is primarily driven by social bonds with other members. (We discuss common bond-based vs. common identity-based communities in the next section.) However, only some elements of this theory have been tested, and the theory does not consider the possibility that increased interaction opportunities and the availability of rich personal information could harm an online community by creating privacy concerns among members. Accordingly, we re-examine and test the theory. From a practical standpoint, we assess whether an emerging de facto standard<sup>2</sup> – that enables online communities and other services to provide users with the option to register using their social network profiles – actually generates value. Our findings are of interest to online communities who have or are considering offering this

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<sup>2</sup> Over 16% of the top 100,000 websites offer the “Login with Facebook” feature. Source: <http://www.leadledger.com/tech/Facebook-Connect> (archived by WebCite® at <http://www.webcitation.org/6QHnToGzo>).

feature as well as to social network platforms that seek to have their integration services more widely adopted.

We state our research question formally as: “Is social network platform integration valuable for a bond-based online community?” We study this by examining the impact of implementing the “Login with Facebook” feature on a bond-based online community in which members interact through customized avatars in 3D spaces; this type of community is often referred to as a social virtual world. Specifically, we examine the effect of the “Login with Facebook” integration on new member registration for the virtual world community and the development of social bonds between members post-registration.<sup>3</sup> The “Login with Facebook” feature allows the virtual world community to “pull” members’ personal information from Facebook as well as to “push” information from the virtual world community back to Facebook. The integration of this feature could generate benefits for the virtual world community by fostering an environment more conducive to social interaction and the creation of social bonds, by enhancing personalization, and by streamlining login and account/profile management. On the other hand, the feature could harm the community by violating members’ privacy and reducing members’ ability to enjoy disinhibition-related benefits from the adoption of online personas distinct from their Facebook profiles.

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<sup>3</sup> “Login with Facebook” is a customer-centric branding of Facebook’s platform integration technology, with other references including Facebook Platform, Facebook Connect, and Facebook Login.

To assess the effect on new member registration, we conducted a randomized field experiment. In the experiment, half of all visitors to the virtual world community's home page were given the option to register using their Facebook accounts, while half were not. The Facebook option reduced new member registration by approximately 11% ( $p < 0.01$ ), which is both statistically and economically significant. Because we used a randomized experiment, we can attribute causality to this relationship. Also, because we conducted the experiment in a "live" field setting, our results have greater external validity than they would have had they been generated in a laboratory. We also examined whether Facebook integration might have an indirect effect on member registration. For example, members who registered with their Facebook accounts might be more likely to post updates about the virtual world community to their Facebook friends (and/or these posts might be system-generated). This online word-of-mouth could generate additional traffic to the virtual world community, which might increase registration volume, even if the registration percentage was reduced. We tested this by examining the number of visitors who arrived at the virtual world community's website by linking from Facebook. Although there was some evidence of a modest increase in visitors coming from Facebook, the increase was insufficient to compensate for the reduction in registrations demonstrated by the experiment. Thus, this hypothetically positive indirect effect could not plausibly offset the negative direct effect of Facebook integration on new member registration.

To assess the effect on the development of social bonds between members, we compared the "friending" behaviors of community members who registered with their Facebook accounts (referred to as "Facebook connected members") to those who did not.

This is important to consider because even if Facebook integration results in fewer members overall, it might engender a member base with unusually strong social bonds, thereby rendering it a net benefit. We found that Facebook connected community members acquired approximately 32% ( $p < 0.01$ ) fewer friends in the virtual world than did non-Facebook connected members. This suggests that Facebook connected members had greater difficulty developing social bonds with others. Although our analysis strategy precludes us from ascribing causality to this portion of our analysis (in contrast to the member registration analysis), we can conclude that Facebook connected community members form less attachment to the community than do members who are not Facebook connected.

In many ways, our findings run counter to theory and expectation. Contrary to theoretical predictions that enhanced social interaction opportunities and rich personal information will help bond-based online communities, we actually find harm, at least when the interaction opportunities and rich personal information stem from social network platform integration. We believe that the negative effect stems largely from information privacy concerns; as a result, future theory construction efforts should explicitly consider this dimension. Also, despite the widespread (and growing) adoption of the “Login with Facebook” feature by online communities and other services across the Internet, we find that this feature is harmful to the online community that we study. We advise online communities and other services to proceed with caution when offering this feature, as it may generate user backlash, particularly in environments where information privacy is important.

## **Literature Review**

There is a rich literature in Information Systems and related fields on online communities (Armstrong and Hagel 2000; Kim 2000; Preece 2000; Smith and Kollock 1999). Information Systems research in this area has focused largely on member participation in and attachment to online communities. From this research, a theoretical understanding of how to design online communities to increase their value is emerging. A key goal of this paper is to contribute to this understanding.

### **Member Participation in Online Communities**

Member participation in an online community may be active or passive. Active participation involves the contribution of content, whether by creating stand-alone information artifacts such as articles, images, or virtual goods or by simply contributing to an online discussion. Passive participation is limited to the consumption of content. Active participation and content creation is important for a community to sustain itself and to generate value for its members (Butler 2001). Several studies have examined how to stimulate active participation. For example, Goodman & Darr (1998) showed that providing search and filter tools that enhance the visibility of content to the appropriate audience encouraged members to contribute reference documents to a knowledge base. Ransbotham & Kane (2011) identified when Wikipedia members engage most actively, and their results suggested that managing member turnover to maintain a steady level of membership at this optimal stage would be positively associated with member contributions. These studies focused on how members contributed information artifacts; other studies have examined how members contributed by participating in discussion forums. For example, Wasko and Faraj (2005) studied an online community of practice and showed that supporting a member's perception of the potential for reputation

enhancement and the value of her<sup>4</sup> knowledge increased her contribution to forum discourse. Ren and Kraut (2014) showed how the level of moderation in discussion forums, such as whether posts were moderated based upon a community standard or whether moderation was customized to an individual member's interests, may elicit higher participation in and commitment to the community. Bateman et al. (2011) applied organizational commitment theory to show that the type of commitment elicited by the online community may determine whether members passively consume or actively contribute to community dialog. The knowledge generated from these studies provides several insights into how to design online communities in an optimal way, such as the importance of designing features and tools that recognize and reward active participation and that help members find relevant content.

### **Attachment to Online Communities**

Ren and colleagues (2012; 2007) built upon social psychology theory and prior research on offline communities to develop several theoretical propositions about how to design an online community to maximize members' attachment to it. Importantly, they recognized that optimal design would vary based on the degree to which members' attachment to the community was motivated by a common identity or a common bond (Prentice et al. 1994). Common identity is formed when members are united by a common sense of purpose, set of goals, or experience (Hogg and Turner 1985; Tajfel and Turner 1985). Common bonds are formed when members form relationships with other

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<sup>4</sup> "She" and "her" are used in the text as gender neutral references.

members in the community (Berscheid and Reis 1998). In the present study, we focus on bond-based online communities, i.e., those designed to emphasize individual relationship formation instead of a sense of common identity. Ren, Kraut, & Kiesler (2007) proposed several theoretical propositions about what factors facilitate members' attachment to a bond-based online community; some have been experimentally validated (Ren et al. 2012). Two of the propositions relevant to the present study relate to: a) social interaction opportunities, and b) disclosure of personal information (Ren et al. 2007). Social interaction refers to the opportunities a community member has to interact socially with others. Increased interaction is posited to increase bond formation among members by providing members with more opportunities to form relationships (McKenna et al. 2002). Opportunities for disclosure refer to the options a community member has to reveal personal information about herself to others. Making personal information available is posited to increase the likelihood that social bonds will form between members by lowering information frictions that would otherwise hinder development of those bonds (Collins and Miller 1994; Ma and Agarwal 2007; Postmes et al. 2002). The proposition about disclosure of personal information has been tested and supported (Ma and Agarwal 2007; Ren et al. 2012). The proposition about social interaction opportunities has not been tested (to our knowledge).

### **Research Gaps**

An increasingly common design decision for online communities is whether to integrate the community with a social network platform such as Facebook, Twitter, and Google+ (Wang et al. 2012). However, the implications of this integration have not been studied. Integration with a social network platform can provide online community members with enhanced social interaction opportunities by helping them involve their

social network “friends” in the community. It can also allow online community members to share rich personal information (including demographics, interests, and social graphs) contained in their’ social network profiles. As a result, studying the integration of a social network platform with an online community provides an opportunity to test the theoretical propositions about social interaction opportunities and disclosure of personal information noted above. Studying this is important because the theory does not consider the possibility that increased interaction opportunities and disclosure of personal data might harm an online community. We discuss this more fully in the next section. It is also important to conduct a test because the proposition related to social interaction has not been tested (to our knowledge).

In addition to contributing to theory about the optimal design of bond-based communities to support participation and attachment, our study addresses a knowledge gap for managers of online communities and other services as well as for social network platforms (e.g., Facebook, Google+). Despite the broad adoption of social network platform integration by online communities, it not clear whether or to what extent this integration actually yields value. Empirical analysis of this value is important for managers of online communities who have integrated or who are considering integrating. It is also valuable to social network platforms who would like for their integration services to be more widely adopted.

### **Theory and Hypotheses**

The goal of this research is to understand whether social network platform integration – as a design consideration – is valuable for an online community by assessing its effects on two essential activities within a bond-based online community:

new member registration and member social bond formation. Because we are considering a bond-based online community, we draw heavily upon the theoretical work of Ren and colleagues.

### **Theoretical Support for and Against Social Network Platform Integration**

Social network platform integration refers to establishing programmatic linkages between an existing online community (or other online service) and a social network platform that enables a bi-directional information flow between them. The online community “pulls” login, profile, and social graph information from the social network platform, and it may also “push” information such as updates on members’ activities within the online community back to the social network platform.<sup>5</sup> The pushing of information from the community to the social network platform may be initiated by the community host or by an individual community member, and may be targeted to all or a subset of the community member’s social network on the social network platform.

In this research, we focus on bond-based online communities, which are communities in which the primary form of member attachment is through relationships with other members of the community (Prentice et al. 1994). This attachment is expressed through participation in the community. In other words, the strength and

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<sup>5</sup> Social network platforms provide APIs that support “pulling” user information from their platforms and “pushing” user activity updates to their platforms. For example, see descriptions of the Facebook Graph API (<https://developers.facebook.com/docs/graph-api>) and the Google+ API (<https://developers.google.com/+api/latest/>) (archived by WebCite® at <http://www.webcitation.org/6QHpiwqJd> and <http://www.webcitation.org/6QHpk04W>).

quantity of the social bonds a member forms with other members strongly determines the extent to which the member participates in the online community.

The bi-directional information flow inherent in social network platform integration has two important implications for a bond-based online community (Ren et al. 2012; Ren et al. 2007). First, social network platform integration provides the functionality for a community member to communicate with her “friends” on the social network platform, whether or not they are also members of the community. This makes it easier for a community member to recruit her social network “friends” for the community, thereby expanding opportunities for social interactions in the community. Second, by increasing the availability of a community member’s personal data from the social network platform to other members of the online community, social network platform integration increases the opportunities for the disclosure and exchange of personal information necessary to form relationships with others. Interpersonal bonds emerge from the disclosure of personal information (Collins and Miller 1994; Postmes et al. 2001). The availability of rich personal information also makes the individual identities of the members composing a community more salient relative to the overall identity of the community, which may further increase bond-based attachment to the community (Utz 2003). A noted example of personal information making individual community members more salient is the availability of photographs of members, such as those which may be brought into an online community by social network platform integration (Farzan et al. 2011).

In addition to the expected benefits of social network platform integration on social bond formation (Kohler et al. 2011; Zhou et al. 2012), there are other reasons why

integration will add value to members of the online community. For example, a potential benefit of social network platform integration is that a community member can leverage her existing profile instead of having to create a new one. This can reduce data entry and eliminate the need to remember an additional user name/password combination, which may be very attractive for members given the high number of user name/password combinations that they typically manage (Sun et al. 2010). Profile information pulled from the social network platform (e.g., age, gender, interests) can also be used to personalize a member's experience, which may make it more satisfying (Awad and Krishnan 2006). The increased social functionality associated with social network platform integration, e.g., the ability to share updates and activities with friends from the social network platform, may increase the sociability of the online community increasing member satisfaction (Animesh et al. 2011; Goel et al. 2011; Kohler et al. 2011). For example, updates from the online service can be automatically shared with friends on the social network platform, and friends from the social network platform can be included in activities in the online service (as is the case with Zynga's separate-from-Facebook gaming platform, zynga.com).<sup>6</sup> Finally, a recent study found that when members belonged to more than one online community the survival rate of both communities improved, suggesting that membership in one community may complement participation in another (Zhu et al. 2014).

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<sup>6</sup> See <http://venturebeat.com/2013/03/21/zynga-will-no-longer-require-facebook-sign-in-on-zynga-com/> (archived by WebCite® at <http://www.webcitation.org/6QHpZ1WOZ>).

Although there are a number of reasons to expect online community member participation to be enhanced by social network platform integration, there is a risk that the increased availability of personal data will lead to privacy concerns that will decrease participation. When deciding whether to join and participate in an online community, prospective members employ a “privacy calculus” where they weigh the benefits of participation against the cost of potentially exposing personal data (Pavlou 2011). Two factors that influence the costs are a member’s individual information privacy concerns and her trust in the online community. Some members may be deeply concerned about maintaining the privacy of their information while others may be more indifferent (Malhotra et al. 2004). The former will attach a higher cost to providing access to her personal information. In addition, some members will be more trusting of the online community to manage their information than will other members, with “trust” defined in this context as beliefs reflecting confidence that personal information will be handled competently, reliably, and safely (Dinev and Hart 2006). Members who trust the online community will attach a lower cost to providing information than will others who do not. Member reservation associated with the two factors of the privacy calculus may be exacerbated by the information’s sensitivity (Li and Pavlou 2013).

In the case of social network platform integration, rich personal data is being made more available, both from the social network platform to the community and vice versa. The type of personal data made available (e.g., name, gender, email address, relationship status, interests/hobbies, product preferences, etc.) is generally considered sensitive (Earp and Baumer 2003). Further, while trust issues for the online community were constrained to member beliefs about community members and the community’s

host, integration with a social network platform adds two additional parties that must be trusted as well: members of the social network platform and the social network platform's host. Collectively, this suggests that integration with a social network platform is likely to increase the burden of perceived benefits to outweigh costs in the privacy calculus.

The potential costs of personal data exposure considered in the privacy calculus may be categorized as general and inhibitory. General privacy costs refer to the risk that specific data will be used in a way that the member does not wish it to be used. The classic example of this type of cost is the risk of fraud being conducted using a person's private information. Inhibitory privacy costs refer to the costs experienced when the availability of personal information inhibits the community member from being able to participate in the community in the manner desired through fear of social consequence. For example, a member's experience may be improved if she uses a persona that is distinct from her persona in the social network platform (Heise 2006; Schultze and Leahy 2009). A separate persona may allow the member to behave in ways that she otherwise wouldn't and that are more reflective of her "true" self (Bessièrè et al. 2007), which can create disinhibition-related benefits (Suler 2004). For example, the separate persona may allow her to pursue online activities that she enjoys but otherwise wouldn't pursue, and it may help her to be more honest about political opinions, sexuality, or other potentially taboo subjects. This desire to "be someone else" may cause community members to prefer fewer, not more, social interaction opportunities from their social network platform "friends". Inhibitory privacy costs may be particularly salient in the case of social platform integration because social platforms typically put processes into place to ensure

the authenticity of their users. Integration with a social network platform may therefore enforce that level of authenticity, and consequent inhibition, upon the integrating community.

## **Hypotheses**

Hypothesis 1 - New Member Registration: Prospective members of a bond-based online community decide whether to participate based upon their perception of current and potential social bonds. Joining a community occurs through a registration process which typically entails a blank online form that must be completed to instantiate membership with the community. When a community is integrated with a social network platform, an additional registration option is made available where a prospective member can choose to join using her existing social network platform profile (this is typical of how integration is deployed; see Figure 1). Prospective members who value some combination of the enhanced social opportunities, disclosure opportunities, account management, and social functionality afforded by integration more so than they devalue the option for the sake of privacy concerns should be expected and additionally motivated to register using the social network platform option. Prospective members who value privacy more may register using the native registration process that was present prior to integration. Since prospective members who see additional value from social network platform integration may choose to leverage it and those who do not may choose to use the service natively as they would have prior to integration, it seems reasonable that social network integration would have a positive effect (or at least a non-negative effect) on new member registration.

*H1: Social network platform integration is positively associated with new member registration.*

Hypothesis 2 - Member Social Bond Formation: Members of the online community who choose to register using their profile from the social network platform will experience enhanced social opportunities and more sharing of personal information, which should help them develop social bonds in the community. Members who do not register using their social network profile will not experience these benefits, although they may enjoy disinhibition-related benefits that make them more social than they otherwise would be. However, on balance, we expect members who register with the social network platform to form more social bonds than members who do not. This is consistent with prior research that has shown that disclosure of personal information enhances the development of social bonds (Ma and Agarwal 2007; Ren et al. 2012).

*H2: Social network platform integration is positively associated with social bond formation.*

### **Research Context**

We operationalized our research question of “is social network platform integration valuable for a bond-based online community” as follows. First, we operationalized “social network platform integration” as integration of the “Login with Facebook” feature by an online community. When implemented by an online community, “Login with Facebook” allows community members to register for and log into the community using their Facebook accounts. As noted in the previous section, this allows the online community to “pull” members’ information from Facebook (including demographics, interests, and social graphs), and it may also “push” information such as updates on members’ activities within the online community back to Facebook. We consider members’ Facebook information to be authentic for the following reasons.

Facebook’s terms of service state that members are required to use only one personal account and that all information provided must be true.<sup>7</sup> In addition, Facebook goes to significant lengths to ensure the authenticity of member accounts, including deletion of illegitimate accounts (Constine 2012).<sup>8</sup> Facebook’s motivation to ensure account authenticity appears to be motivated by its desire to have accurate profiles for its advertising programs, as well as its desire to serve as an authority for user identification and authentication across the Internet (Garfinkel 2011). Figure 1 shows an example of an online community that provides the option to log in with Facebook. This feature is widely adopted across the Internet, with major sites such as Yahoo, Netflix, Groupon, and Skype offering it (surprisingly, there is little academic research examining this feature). Second, we operationalized whether social network platform integration is “valuable” by considering its effect on new member registration and member social bond formation, as discussed in the last section. Third, to explore the implications of social network platform integration on a “bond-based online community”, we worked with a firm located in the southeast United States that operates an online community in which members interact through customized avatars in 3D spaces, i.e., a virtual world.<sup>9</sup> The firm designed and markets the virtual world as a social environment in which to interact with and meet new friends, i.e., as a bond-based online community. “Friending” – in which member A asks

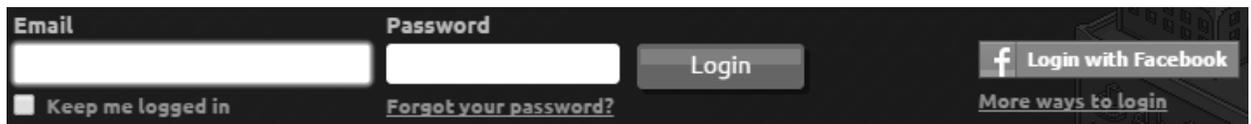
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<sup>7</sup> See <https://www.facebook.com/legal/terms> (archived by WebCite® at <http://www.webcitation.org/6QHpURsCi>).

<sup>8</sup> Also see <https://www.facebook.com/notes/facebook-security/improvements-to-our-site-integrity-systems/10151005934870766> (archived by WebCite® at <http://www.webcitation.org/6QHp3Keu9>).

<sup>9</sup> The operator of the virtual world prefers to remain anonymous.

member B to be her “friend” and member B accepts or declines – is common in the virtual world community. Members with no prior relationship frequently meet and friend each other “in-world”, where they form relationships based on the virtual setting and how they choose to present themselves to each other. Common activities in the virtual world include exploring, playing games, and attending parties at virtual dance clubs and related venues. Members often conduct these activities with other members: feedback solicited by the firm show that social activities and social bonds are prominent sources of member value.



**Figure 1: Example of an Option to Log in to an Online Community with Facebook**

Another attractive feature of the virtual world community for our purposes is that it reflects the tension that underscores our hypotheses. For example, there are many potential benefits to social network platform integration in the virtual world community, including creating social interaction opportunities, enriching the environment for creating social bonds, enabling enhanced personalization, and providing streamlined login and account/profile management. There are also potential drawbacks, including loss of privacy and reduced ability to enjoy disinhibition-related benefits from the adoption of a new online persona. Thus, the effect of social network platform integration on this community is non-obvious.

### **Data, Analysis, and Results**

In 2012, the firm that operates the virtual world expressed an interest in integrating with Facebook. They believed that the potential benefits to their community were large enough to implement and test the “Login with Facebook” feature. We worked with the firm to assess the impact of the “Login with Facebook” option on new member registration and social bond formation. We used multiple methods in our investigation, including a randomized field experiment and analysis of archival data.

### **Effect of Social Network Platform Integration on New Member Registration**

Integration of a social network platform into the virtual world community may impact new member registration in two ways. First, it may affect the percentage of visitors to the virtual world community who register. We analyze this effect through a randomized field experiment. Second, it may affect the volume of prospective new members who visit the virtual world community. We explore this possibility by analyzing web referral traffic to the virtual world community over time.

#### Direct Effect of Social Network Platform Integration: Randomized Field Experiment

*Background:* We worked with the virtual world operator to conduct a randomized field experiment to measure the effect of “Login with Facebook” integration on the rate of new member registration.

Figure 2 shows the process by which visitors to the website participated in the experiment. During the experiment, visitors to the firm’s website were randomly assigned to and consistently presented with either the control or treatment versions of the website. The control version prompted visitors to create an account for the virtual world using the firm’s native account management system. The treatment version was functionally identical except that it also provided visitors with the option to create an account using their Facebook accounts. Visitors choosing to register natively (in both the control and

treatment conditions) received a web page with a blank registration form, which they could manually complete to finish registration. Visitors choosing to register using Facebook received prompts to log into Facebook (if they were not already logged in), after which they were prompted to grant the virtual world permission to: a) access their Facebook profile data (i.e., to “pull” information), and b) post status updates to Facebook (i.e., to “push” information); see

Figure 2. Upon approval, the visitor was presented with a registration page that was largely populated with information from her Facebook profile. Browser cookies ensured that each unique visitor saw the same version of the website if they returned.

Figure 2 shows that the treatment version differs from the control version in two key ways: a) the presence of the Facebook option, and b) a change in the label for the “native” registration option from “Start Now” to “Sign up with Email”. Had we conducted this study in an artificial lab environment, we might have taken the control version and simply added the Facebook option – without making any other changes – to create the treatment version. That would allow us to ensure that any treatment effect was solely due to the presence of the Facebook option and not to screen formatting differences.

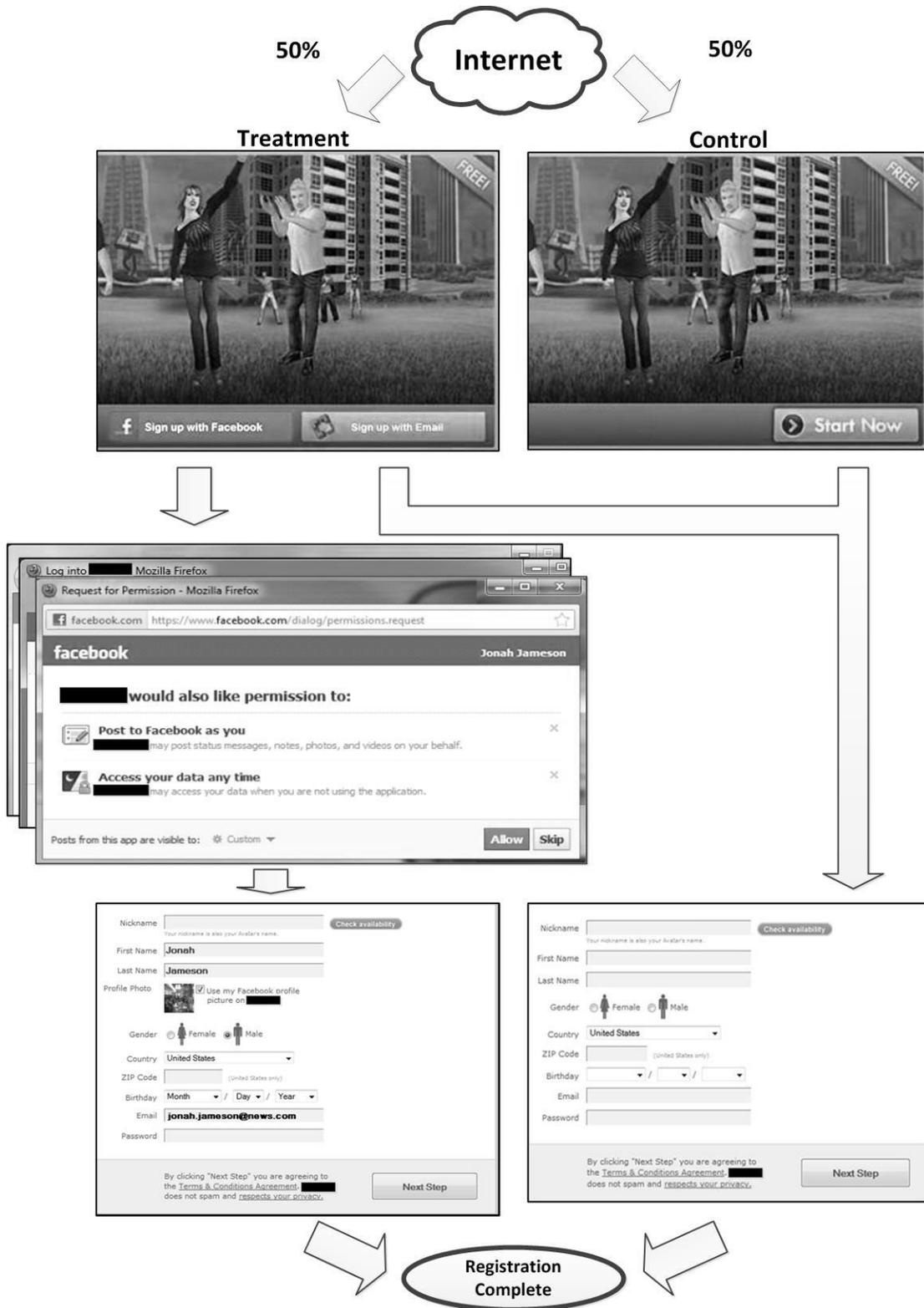


Figure 2: Experiment Process (Name of Virtual World Redacted)

However, because we conducted the study in the field – using the live website and real visitors – this was not possible, nor necessarily desirable. The design we used was necessary to maintain the realism required for a live field experiment and reflects how social network platform integration is implemented. Viz., the native registration button must be changed to distinguish it from the new social network platform option, whereas prior to integration the button needs less distinction given the lack of an alternative. We discuss this further in the conclusion.

We used power analysis to compute the necessary sample size for the experiment. We assumed an effect size of a 10% change in the registration rate, a 5% chance of committing a type-I error (i.e.,  $\alpha = 0.05$ ), and a power of 0.9 or better. Given these parameters, the minimum sample size was 19,418 total subjects, half in the control group and half in the treatment group. We ran the experiment from the morning of 7/26/2012 to the morning of 7/31/2012, yielding a sample size of 24,923. There were 12,372 website visitors in the control group and 12,551 in the treatment group. In expectation, each experimental group should be composed of 50% of the total visitors, or 12,461.5 visitors. Both 12,372 and 12,551 lie within the 95% confidence interval surrounding 12,461.5, indicating that the experimental randomization worked properly.<sup>10</sup>

*Results and Interpretation:* We measured *Registration Rate* for each experimental group as the number of unique visitors who completed the registration process divided by

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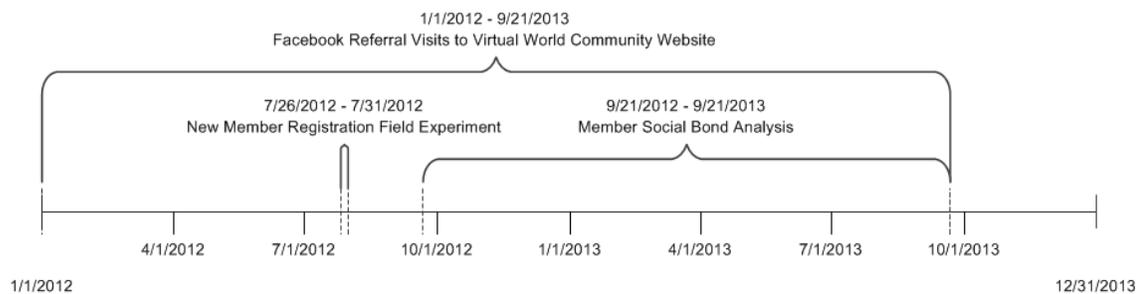
<sup>10</sup> The number of visitors placed into the treatment group follows a binomial distribution with  $p=0.5$ . As such, we calculated the 95% confidence interval [12307, 12616] using the normal approximation for a binomial distribution.

the total number of visitors. *Registration Rate* for the control group (No Facebook Option) was 17.2%, while *Registration Rate* for the treatment group (Facebook Option) was 15.3%. A two-sample test of proportions showed that this difference is significant at  $p < 0.01$ . The treatment reduced the registration rate by 11% (i.e.,  $(17.2\% - 15.3\%) / 17.2\% \approx 11\%$ ), which is practically significant given the importance of the member base to the virtual world community. Thus, we find no support for H1.

The negative effect of the Facebook option is surprising because subjects in both the control and treatment groups had the option to register with a native account. Because the treatment simply offered an additional option that subjects could easily ignore, one might expect the treatment to have no effect or a positive effect. However, it may be that the mere presence of Facebook dissuades prospective members from registering, even natively. In particular, a prospective member may anticipate that even if she is not connected to Facebook, other members with whom she will interact may be connected. This may represent enough of an interconnection to Facebook to deter prospective members with information privacy concerns from registering. For example, a non-connected member's activities could still be chronicled on Facebook via posts from a connected member with whom she shares these activities.

Immediately following the conclusion of the experiment, the firm chose to implement the "Login with Facebook" option for all prospective visitors, while still providing members the option to create a native account. "Login with Facebook" remained available throughout the duration of our analysis, which extends to September 2013.

Figure 3 depicts the time spans used for different aspects of the analysis, including the randomized field experiment. Although providing the Facebook option for registration ran counter to the results of the experiment, the firm thought that Facebook integration might generate other benefits, including improving member attachment to the community as well as generating viral marketing to attract new members who would not otherwise consider joining the virtual world community. We consider these possibilities below.



**Figure 3: Date Ranges of Data Considered**

Indirect Effect of Social Network Platform Integration: Referral Traffic

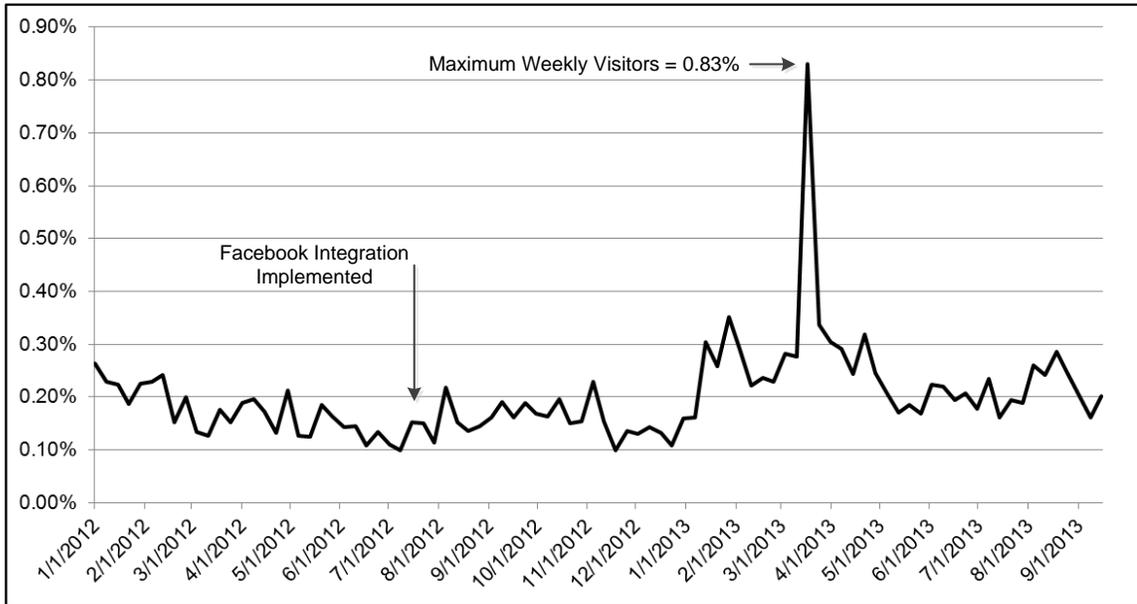
It is possible that integration with Facebook may affect the number of prospective new members visiting the virtual world community website. For example, members who integrate with Facebook might post status updates about their experience in the virtual world community to their Facebook page (this might occur automatically), thereby generating viral marketing that attracts prospective new members from their social network (Aral and Walker 2011). Given that the presence of the “Login with Facebook” option decreases the percentage of visitors who register by approximately 11%, we examined whether increased referral traffic could make up for that loss. In other words,

even if Facebook integration reduces the *percentage* of visitors who register, it could still have a net positive effect on registration by increasing the *number* of visitors.

To examine this, we re-interpreted the effect size of the “Login with Facebook” treatment from our experiment as a 1.9 *percentage point* decrease in *Registration Rate* (i.e.,  $17.2\% - 15.3\% = 1.9$ ), which is equivalent to the 11 *percent* decrease noted above. A useful way to think of this is that in any given week  $t$ , there is a group that comprises 1.9% of the overall visitors to the virtual world website that would have registered but that do not because of the Facebook option (recall that the firm offered the Facebook option to all visitors after the conclusion of the experiment). To compensate for that loss, Facebook integration would have to yield enough incremental referral traffic to replace that 1.9% of the overall visitors. To examine this, we used the virtual world’s web server logs to calculate the percentage of visitors who came to the virtual world website from Facebook.com for each week  $t$  from January 1, 2012 to September 21, 2013.

Figure 4 shows this time series. The percentage declines slightly until the Facebook integration was implemented, after which it increases slightly. This suggests that Facebook integration might have led to more referral traffic from Facebook.com, although the observed trends could also reflect changes in Facebook’s overall popularity or other factors. However, even at its highest point during the week of 3/17/2013, the percentage is only 0.83%. Thus, even if we make the (fairly implausible) assumptions that all of these referred visitors are incremental (i.e., would not have otherwise come without the Facebook integration) and that all of them register for the virtual world community, then this indirect effect of Facebook integration would only compensate for (at most) 43% of the lost members. Thus, we find no evidence that Facebook integration

induced sufficient referral traffic to offset the decrease in registration demonstrated by the experiment.



**Figure 4: Percentage of Visitors to the Virtual World’s Website from Facebook 1/1/2012 – 9/21/2013**

### **Effect of Social Network Platform Integration on Member Social Bond Formation**

The above results show that Facebook integration is negatively associated with new member registration. However, it is possible that those members who register with their Facebook accounts contribute disproportionately to the social bonds within the virtual world community, which might offset the negative effect of reduced registration. We explored that possibility by considering how members’ social bond formation with others in the virtual world community differed based on whether they registered with Facebook or not.

*Background and Variables:* We collected virtual world behavioral data (including social bond behavior as well as time spent using the virtual world) for all new members

who registered between 9/21/2012 and 9/21/2013 (n=75,648). We used this period due to data availability and because it occurred after the virtual world had fully deployed the “Login with Facebook” registration option. To permit comparison of behavior across members, we measured each member’s behavior for her first seven calendar days starting with the day she registered. We used the first seven days to provide sufficient time for new members to get acquainted with the virtual world community. Seven days is also generally seen as a key formative period, as reflected by the standard online service metric of “Returned after 7 Days” (Vidyarthi 2010). However, we also verified that the results are robust to using post-registration time windows of 1, 3, 30, and 60 days. We discuss this and other robustness checks below.

We examined member’s social bond formation by looking at their “friending” behaviors. We considered three measures: a) *Requests Issued* is the number of friend requests the member issued (i.e., the outdegree measure), b) *Requests Received* is the number of friend requests the member received (the indegree measure), and c) *Friends Acquired* is the number of friends the member acquired. Note that *Friends Acquired* is generally different from the sum of *Requests Issued* and *Requests Received*. The only time it would be the same is if the member accepted all the friend requests she received and had all of her requests accepted. The key independent variable, *Facebook Connected*, is an indicator for whether a member registered for the virtual world community using her Facebook account. Because these data were collected after the experiment, all prospective new members were presented with both the native and Facebook options during registration. Approximately 9% chose to integrate with Facebook during registration. Gender (coded as *Female*=1 for females) and age are self-reported control

variables. We divided *Age* into bins (e.g., Age 12-17, Age 18-24, etc.) to examine the age distribution of members in the virtual world. *Day Registered* represents the day the member registered; e.g., *Day Registered* = 1 for 9/21/2012, and *Day Registered* = 366 for 9/21/2013. *Minutes Online* is the number of minutes each member spent in the virtual world community in the first 7 days. Table 1 shows a summary of the variables.

**Table 1: Variables and Descriptive Statistics**

|                    | Median | Mean   | Std. Dev. | Min. | Max. |
|--------------------|--------|--------|-----------|------|------|
| Friends Acquired   | 0      | 2.40   | 8.90      | 0    | 608  |
| Requests Issued    | 0      | 1.93   | 9.81      | 0    | 871  |
| Requests Received  | 0      | 1.09   | 3.27      | 0    | 91   |
| Minutes Online     | 5.28   | 15.13  | 44.67     | 0    | 2477 |
| Facebook Connected | 0      | 0.09   | 0.29      | 0    | 1    |
| Female             | 1      | 0.56   | 0.50      | 0    | 1    |
| Age                | 19     | 22.00  | 9.79      | 12   | 73   |
| Age 12-17          | 0      | 0.36   | 0.48      | 0    | 1    |
| Age 18-24          | 0      | 0.42   | 0.49      | 0    | 1    |
| Age 25-34          | 0      | 0.12   | 0.33      | 0    | 1    |
| Age 35-44          | 0      | 0.05   | 0.23      | 0    | 1    |
| Age 45-54          | 0      | 0.02   | 0.15      | 0    | 1    |
| Age 55-64          | 0      | 0.01   | 0.10      | 0    | 1    |
| Age 65+            | 0      | 0.01   | 0.10      | 0    | 1    |
| Day Registered     | 170    | 175.03 | 105.60    | 1    | 366  |
| Observations       | 75648  |        |           |      |      |

See text for variable definitions.

*Analysis:* We began by conducting a t-test for each of the “friending” variables to determine whether there is a difference between those members who are Facebook connected and those who are not. Table 2 shows that Facebook connected members are, on average, less socially engaged than those members who are not connected to Facebook.<sup>11</sup> Facebook connected members make 0.79 fewer friends (a 32% reduction),

<sup>11</sup> We also compared the dependent variables across the two user groups via Wilcoxon (Mann-Whitney) rank-sum tests. Results are consistent.

issue 0.61 fewer friend requests (a 30.7% reduction), and receive 0.36 fewer friend requests (a 32.1% reduction). Each of these differences is statistically significant at  $p < 0.01$ . Given our relatively large sample size, we report the percentage differences to illustrate that the differences are practically significant as well as statistically significant. This reduced bond formation is particularly meaningful given that the first 7 days is a key formative time that shapes members' experiences (as noted above, results are robust to other window sizes). Overall, community members who register with Facebook are less socially engaged in the virtual world community than those who do not.

**Table 2: Member Social Bond Formation: T-Test Results**

|                                    | Mean for members who are Facebook Connected | Mean for members who are Not Facebook Connected | Difference | % Reduction | t     | p    |
|------------------------------------|---|---|------------|-------------|-------|------|
| Dependent Variables (Social Bonds) |   |   |            |             |       |      |
| - Friends Acquired                 | 1.68  | 2.47  | -0.79      | 32.0%       | -7.08 | 0.00 |
| - Requests Issued                  | 1.38  | 1.99  | -0.61      | 30.7%       | -4.96 | 0.00 |
| - Requests Received                | 0.76  | 1.12  | -0.36      | 32.1%       | -8.75 | 0.00 |
| Observations                       | 75648                                       |   |            |             |       |      |

All statistics are rounded to two digits.

We used regression to examine whether the differences shown in the t-tests are robust to the influence of demographic, temporal, and other factors. We control for self-reported gender and age, using *Age* bins to allow the effects of age to be non-linear, with *Age 12-17* as the base case.<sup>12</sup> We control for *Day Registered* (via fixed effects for each

<sup>12</sup> For robustness, we also performed regressions with *Age* as a linear term and found that the coefficient was positive and significant, with other coefficients being substantively unchanged.

day, depicted in the model below as  $\sum_{i=2}^{366} \beta_{9,i} \text{Day Registered}(i)$  to account for the potential for fluctuations in the virtual world experience over time. We also control for the length of time a member is logged into the community via *Minutes Online*.

The regression model is:

$$\begin{aligned}
 DV = & \alpha + \beta_1 \text{Facebook Connected} + \beta_2 \text{Female} + \beta_3 \text{Age 18-24} & (1) \\
 & + \beta_4 \text{Age 25-34} + \beta_5 \text{Age 35-44} + \beta_6 \text{Age 45-54} + \beta_7 \text{Age 55-64} \\
 & + \beta_8 \text{Age 65+} + \sum_{i=2}^{366} \beta_{9,i} \text{Day Registered}(i) + \beta_{10} \text{Minutes Online} + \varepsilon
 \end{aligned}$$

Because the dependent variables are integers, we used negative binomial regression to account for over dispersion and the high number of zero values.<sup>13</sup> Table 3 shows the results. All coefficients for *Facebook Connected* are negative and significant, with their marginal effects comparable to the differences shown in the t-tests. Thus, we find no support for H2.

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<sup>13</sup> We also used OLS for all models. Results are similar to the negative binomial results that we report.

**Table 3: Regression Results for Member Social Bond Formation**

|                                  | Friends Acquired     |                              | Requests Issued      |                              | Requests Received    |                              |
|----------------------------------|----------------------|------------------------------|----------------------|------------------------------|----------------------|------------------------------|
|                                  | Coefficient Estimate | Marginal Effect <sup>a</sup> | Coefficient Estimate | Marginal Effect <sup>a</sup> | Coefficient Estimate | Marginal Effect <sup>a</sup> |
| Facebook Connected               | -0.316***<br>(0.034) | -0.591***<br>(0.064)         | -0.292***<br>(0.043) | -0.442***<br>(0.065)         | -0.307***<br>(0.033) | -0.262***<br>(0.028)         |
| Female                           | 0.133***<br>(0.020)  | 0.249***<br>(0.037)          | -0.001<br>(0.025)    | -0.002<br>(0.038)            | 0.317***<br>(0.019)  | 0.271***<br>(0.016)          |
| Age 18-24                        | -0.020<br>(0.022)    | -0.038<br>(0.041)            | -0.051*<br>(0.028)   | -0.077*<br>(0.042)           | 0.037*<br>(0.021)    | 0.032*<br>(0.018)            |
| Age 25-34                        | -0.042<br>(0.032)    | -0.078<br>(0.060)            | -0.102**<br>(0.040)  | -0.155**<br>(0.061)          | 0.052*<br>(0.031)    | 0.045*<br>(0.026)            |
| Age 35-44                        | -0.087*<br>(0.045)   | -0.163*<br>(0.085)           | -0.170***<br>(0.057) | -0.257***<br>(0.086)         | 0.051<br>(0.042)     | 0.044<br>(0.036)             |
| Age 45-54                        | -0.392***<br>(0.066) | -0.734***<br>(0.123)         | -0.635***<br>(0.083) | -0.962***<br>(0.126)         | -0.042<br>(0.062)    | -0.036<br>(0.053)            |
| Age 55-64                        | -0.329***<br>(0.104) | -0.615***<br>(0.194)         | -0.362***<br>(0.131) | -0.549***<br>(0.198)         | -0.134<br>(0.097)    | -0.114<br>(0.083)            |
| Age 65+                          | -0.202*<br>(0.103)   | -0.377*<br>(0.193)           | -0.322**<br>(0.129)  | -0.487**<br>(0.196)          | 0.054<br>(0.097)     | 0.046<br>(0.083)             |
| Minutes Online                   | 0.025***<br>(0.001)  | 0.047***<br>(0.001)          | 0.024***<br>(0.001)  | 0.037***<br>(0.001)          | 0.023***<br>(0.000)  | 0.020***<br>(0.000)          |
| Constant                         | 0.134<br>(0.179)     |                              | 0.095<br>(0.220)     |                              | -0.823***<br>(0.171) |                              |
| Fixed effects for Day Registered | Included             |                              | Included             |                              | Included             |                              |
| Observations                     | 75648                | 75648                        | 75648                | 75648                        | 75648                | 75648                        |
| Log Likelihood                   | -113170.2            |                              | -91584.1             |                              | -87414.7             |                              |

Model estimated via negative binomial regression.

Standard errors in parentheses; \* p < 0.10, \*\* p < 0.05, \*\*\* p < 0.01; two-tailed test.

<sup>a</sup> Marginal effects represent the expected change in the dependent variable due to a one-unit increase in the independent variable (which is the change from 0 to 1 for an indicator variable).

*Potential Endogeneity: Facebook Connected* may be endogenous in the regression shown in equation (1). For example, there may be an omitted variable(s) that influences both the social bond dependent variables (*Friends Acquired*, *Requests Received*, and *Requests Issued*) and *Facebook Connected*. We do not attempt to correct for this econometrically, as we do not have access to a valid instrumental variable, there is no available natural experiment to exploit, etc. As a result, our estimate of  $\beta_1$  may be biased.

Here, we explore whether this potential bias could invalidate our conclusion that social platform integration has a negative impact on social bond formation.

Consider that our estimate of  $\beta_1$  might be unbiased, positively biased, or negatively biased. If our estimate of  $\beta_1$  is unbiased, then there is no concern. If our estimate of  $\beta_1$  is positively biased, then our result underestimates the true effect of *Facebook Connected*. In this case, our overall conclusion – that social platform integration has a negative impact on social bond formation – remains valid, although the effect of *Facebook Connected* will be even more negative than we document. If our estimate of  $\beta_1$  is negatively biased, then our result overestimates the true effect of *Facebook Connected*, which might be insignificant or even positive (if the bias is very large). However, consider what would have to be true for this to be the case. Our results show that Facebook connected members acquire 32% fewer friends than non-connected members (see Table 2). If the true effect of *Facebook Connected* on social bond formation was positive, then it must be true that Facebook connected members would have acquired even fewer friends had they *not* registered with Facebook. This would mean that Facebook integration would be attracting members of unusually low “friendliness” that is not fully remediated by the (hypothetically positive) effect of Facebook. When considered in conjunction with the experimental finding that Facebook integration results in fewer members overall, this would mean that integration not only reduces the number of community members, but it also shifts the inherent sociability of that reduced number of members in a negative direction. In this case, Facebook integration has a negative impact on the overall social bond formation of the community. In summary, even though

we do not econometrically adjust for the potential endogeneity of the *Facebook Connected* variable, we believe that our overall conclusion remains valid.<sup>14</sup>

*Robustness Checks:* We ran several robustness checks. First, it is possible that the effect of Facebook integration varies over the course of the year, such that considering only the aggregated data for the entire year masks interesting temporal variation. To test this possibility, we ran separate regressions for each quarter of the one-year period and verified that the results were consistent for each quarter. Second, it is possible that the difference between the Facebook connected and non-connected members may vary depending on the duration of the post-registration period considered. We used a 7-day period in our focal analysis, and we verified that the results were robust to considering periods ranging from 1 to 60 days. Third, we conducted a matching analysis in which we matched Facebook connected members to non-Facebook connected members. We exact matched connected to non-connected members on gender, age, and registration date. This

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<sup>14</sup> We can examine the potential bias of  $\beta_I$  more formally via the formula for omitted variable bias:  $\hat{\beta}_1 = \beta_I + \gamma\delta_I$  (see Wooldridge (2002, section 4.3.1)).  $\hat{\beta}_1$  is the estimated (and potentially biased) coefficient,  $\beta_I$  is the true (unbiased) coefficient,  $\gamma$  is the partial correlation between the omitted variable(s) and the dependent variable, and  $\delta_I$  is the partial correlation between the omitted variable(s) and *Facebook Connected*. If either  $\gamma$  or  $\delta_I$  is zero, then  $\hat{\beta}_1$  is unbiased. If  $\gamma$  and  $\delta_I$  are both positive or both negative, then  $\hat{\beta}_1$  is positively biased, such that the true  $\beta_I$  is even more negative than we estimate. I.e., our overall conclusion will remain valid, but our effect size estimate will be imprecise. If either  $\gamma$  or  $\delta_I$  is positive while the other is negative, then  $\hat{\beta}_1$  is negatively biased, such that the true  $\beta_I$  might be insignificant or even positive. Because this is the only scenario that might invalidate our overall conclusion, we study it more carefully. If  $\gamma > 0$  and  $\delta_I < 0$ , the omitted variable(s) increases bond formation while decreasing the likelihood of being *Facebook Connected*. Similarly, if  $\gamma < 0$  and  $\delta_I > 0$ , the omitted variable(s) decreases bond formation while increasing the likelihood of being *Facebook Connected*. In either case, users who integrate with Facebook would be of low value in terms of their attachment to the virtual world community, thereby negatively affecting the community.

exact matching limits demographic variation within the pair, and it ensures that both members experienced the virtual world during the same 7-day time period. This means that environmental conditions of the virtual world that change over time and that might influence social bond formation – such as how many other members were active during a given period, how many parties were held during the period, etc. – were the same for both members. We used coarsened exact matching (Iacus et al. 2012) to include *Minutes Online* in our matching criteria. We coarsened *Minutes Online* into bins for each quartile and matched Facebook connected and non-connected members in the same bin. This yielded 5080 matched pairs. Using this matched sample, we reran the t-tests and regression models. Results are consistent with those reported above.

We also replicated our social bond analysis using variables that measure how long members spent using the virtual world community. Consistent with the above analysis of social bond formation, Facebook connected members spent significantly less time in the virtual world than did non-Facebook connected members. See the appendix for details.

### **Conclusion**

In this research, we posed the question: “Is social network platform integration valuable for a bond-based online community?” To address the question, we examined how integration of the “Login with Facebook” feature into an online virtual world community affected new member registration and member social bond formation. Using a randomized field experiment, we found that Facebook integration reduced the rate of new member registration by 11%. Although it might be possible for Facebook integration to generate referral traffic that could effectively mitigate or overturn this loss, the evidence suggests that this did not occur. Using archival data, we found that members

who registered using Facebook formed fewer social bonds than others who did not. This result was robust to multiple measures of social bond formation and participation, the influence of potentially confounding covariates, specification choice, and timeframe considered. Overall, social network platform integration was a net loss in our study: it resulted in fewer and less attached members in the community.

### **Discussion and Implications**

Our analysis contributes to both theory and practice. First, existing theory (Ma and Agarwal 2007; Ren et al. 2012; Ren et al. 2007) posits that enhanced social interaction opportunities and the availability of rich personal information about members (including demographics, interests, and social graphs) – which is precisely what social network platform integration provides – will benefit a bond-based online community by facilitating the development of interpersonal relationships. However, the theory does not consider the possibility that personal information might *harm* the online community by creating information privacy concerns among members. As a result, an empirical investigation is important for testing and extending theory about the design of online communities. Somewhat surprisingly, we find that the personal information and expanded interaction opportunities made available via social network platform integration was harmful to the online community. It may be that rich personal information *is* beneficial to a bond-based online community, but only when that information is doled out by the members of the community on a voluntary basis – not when it is imported en masse from another, potentially unrelated repository such as a social network platform. To that end, a promising avenue for future research is to compare the effect of personal information and social interaction opportunities when they

are produced organically within the community vs. when they are drawn from an external source.

Our results also have implications for practice. Despite the rapidly growing acceptance of social network platform integration as a de facto standard, our results suggest that online communities (and other services) should be wary of potential negative implications for both member registration and member behavior. This may be particularly true for communities where members value anonymity or pseudonymity. Online communities should consider whether a social network platform's context is compatible with their community when deciding whether integration would be beneficial. Our results are also relevant to social network platforms seeking to increase adoption of their login service. A key goal of these services is to provide the social network platform with visibility to user activity across the Internet. However, this tracking capability may dissuade users and online communities from adopting the service. Our results highlight the need for social network platforms to examine the information exchanged between online communities and the platform. Consistent with this, Facebook is reportedly implementing an option to allow a user to log into third-party services with her Facebook account without the third-party having access to the details of her Facebook profile.<sup>15</sup> Finding the right balance could provide users with the benefits of leveraging their existing social network profile while mitigating concerns about information privacy.

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<sup>15</sup> See <http://www.nytimes.com/2014/05/01/technology/facebook-to-let-users-limit-data-revealed-by-log-ins.html> (archived by WebCite® at <http://www.webcitation.org/6QHpcMAkr>).

## **Limitations and Future Research**

A limitation of our study is that our results are specific to our empirical context; this is a common limitation of empirical research. However, we believe the community that we study is representative of other bond-based online communities. The theoretical arguments about whether social network platform integration will benefit or harm the online community are general and will apply to multiple settings. Nevertheless, future research that replicates our analysis in other settings will generate new empirical results that may add nuance to our understanding of the conditions under which social network platform integration benefits or harms the adopting online community. Another limitation stems from a design trade-off associated with the field experiment setting. Running the experiment in the field with the virtual world operator ensured realism and adds to the study's external validity. However, the price of maintaining realism is that we are not able to determine whether the mechanism behind the negative effect of Facebook integration on new member registration is the Facebook option per se or other formatting differences between the control and treatment conditions. However, we are skeptical that the formatting differences are responsible for the negative effect for two reasons: a) the differences are relatively minor, and b) there is little theory to suggest why the formatting differences would create the substantial reduction (11%) in the member registration rate that we observe. In contrast, the literature suggests that social theory is likely to dominate usability factors (Lampe et al. 2010; Wang and Chen 2012), and a recent meta-analysis of the impact of providing additional choices (as in the treatment condition) showed an insignificant mean effect (Scheibehenne et al. 2010). Also, our design is representative of how Facebook integration is implemented in the field, such that if a negative effect comes from formatting differences, this negative effect is likely to exist for other online

communities / services that implement Facebook integration. A limitation of our archival data analysis is that given the potential endogeneity of the *Facebook Connected* variable, we cannot comment on whether Facebook integration *causes* lower social bond formation in the virtual world community. However, we can still conclude that Facebook connected members have fewer social bonds than non-Facebook connected members. When coupled with the finding that Facebook integration leads to fewer members, our conclusion that Facebook integration yielded a net loss is valid. Future research can seek to identify a causal connection between Facebook integration and members' social bonds.

## **CHAPTER 3: THE IMPACT OF AN OPEN TECHNOLOGY STANDARD ON THE DEFENSE AVIONICS INDUSTRY**

### **Introduction**

U.S. defense avionics is a multi-billion dollar industry whose performance has significant social welfare implications in terms of national security, economics, taxes, fringe industry interactions, and the emergence of new technologies. Military aircraft<sup>16</sup> feature both a high initial acquisition cost and a high maintenance cost accumulated over a lifespan that may reach 80 years before retirement.<sup>17</sup> The evolving sophistication of these aircraft, and consequently the cost, is increasing determined by the aircraft's software (Arena et al. 2008).

The high cost of defense avionics software is broadly attributed to an approach to software development that is highly proprietary. Firms build software that is custom to a given project's requirements with minimal consideration for the inevitable updates and changes that will be required over the aircraft's long lifespan. When an update to the existing software is needed, the contracting agency is often faced with two suboptimal rational choices: pay the original developer to adjust or replace their software, or pay for

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<sup>16</sup> In this work the term aircraft is used generically to refer to aircraft models, such as the F-22 Raptor or B-1 Bomber, rather than to specific physical implementations of those aircraft.

<sup>17</sup> See <http://www.defenseindustrydaily.com/aging-array-of-american-aircraft-attracting-attention-0901/> (Archived by WebCite® at <http://www.webcitation.org/6ZDJbiiHH>) and <http://www.businessinsider.com/chart-shows-hourly-cost-of-military-aircraft-2014-12> (Archived by WebCite® at <http://www.webcitation.org/6ZDJzFBYY>)

a replacement of the software, with that replacement itself being another custom and proprietary solution. This cycle repeats throughout the lifespan of the aircraft.

To address this challenge, the U.S. military formed a coalition of industry firms to collaboratively develop an open technology standard for defense avionics software. The goal of this initiative is to supplant the current pattern of generating one-off solutions through current proprietary and custom development practices with the creation of reusable software artifacts. The literature supports this possibility, suggesting that the use of open technology standards may foster the creation of artifacts that are more valuable due to their broader applicability as product solutions, which in turn may foster increased competition on price and thereby cost (Katz and Shapiro 1994). The use of an open technology standard may also encourage the maturing of related development practices and provide direct efficiencies, for example by making project knowledge and expertise more portable (Garud et al. 2009).

While the theoretical expectations of open technology standard use are generally established, there is minimal research validation of these expectations. Rather, most work on open technology standards is conceptual. In this work we contribute to research on open technology standards by exploring its impact on an industry scale. We seek to answer the question: *What is the impact of the adoption of a consortium-derived open technology standard on software development project effort?*

A major challenge in characterizing this type of impact is that strong contextual factors specific to the industry examined should be expected (Joglekar et al. 2015). Indeed, there is growing recognition that the study of an industry may need to accept that an industry itself is sufficient scope given that it is unlikely that complexities of those

contextual factors can be sufficiently controlled for.<sup>18</sup> Studying a single industry is justified when the industry under consideration is sufficiently 1.) distinct and 2.) important. The U.S. defense avionics industry clearly meets both criteria.

At the time of this study the defense avionics industry was in the preliminary stages of what is expected to be a lengthy adoption process given the long time frames of projects. This extended adoption window means that it may be 10-20 years before sufficient empirical data becomes available to assess the impact of the open technology standard. In short, the industry may be well vested in their use of the standard long before empirical validation of its value can occur. This challenge is further exacerbated by protectionist policies that currently (and may still in future) limit access to industry project data.

To address these challenges, we use the Delphi method to forecast the impact of the open technology standard by building a consensus estimate of this impact by a representative set of industry experts (Okoli and Pawlowski 2004). This is valuable in two ways. First, it provides insight into the perspective of industry firms as to the impact. This perspective will shape the decisions being made to address the change the use of the open technology standard represents. Second, it provides the best available estimate of the true impact of the open technology standard.

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<sup>18</sup> A division of the Production and Operations Management (POM) Journal was initiated for this reason: [http://www.poms.org/2006/12/industry\\_studies\\_public\\_policy.html](http://www.poms.org/2006/12/industry_studies_public_policy.html) (Archived by WebCite® at <http://www.webcitation.org/6ZDWTAWyr>)

In this work we make two essential contributions to the information systems literature. First, we provide empirical validation and quantification of prior theory that is largely conceptual (see Brynjolfsson et al. for a good example of the value of quantification (Brynjolfsson et al. 2003)). Although theory around change management and learning curves is well established, there is limited empirical understanding of the scale and period of these curves (Fong Boh et al. 2007; Todnem By 2005). Similarly, research on standards has a track record that extends decades, however, the essential precept that standards reduce costs has suffered limited testing. In this study we empirically characterize learning curves and tests the precepts that suggest standards use is beneficial. Second, we answers Hevner et al.'s call for IS research that generates IT artifacts that are valuable to research and practice by providing a method for forecasting the impact of technology changes to project effort (von Alan et al. 2004). While the approach is tailored in this work to a specific industry, technology change, and project type, the method demonstrated here can be customized to a number of contexts. This method provides substantial theoretical and practical benefits by providing a way to test for predicted effects (and firm constituent belief in them) of a large scale technology change to project characteristics and costs.

### **Literature Review and Foundation**

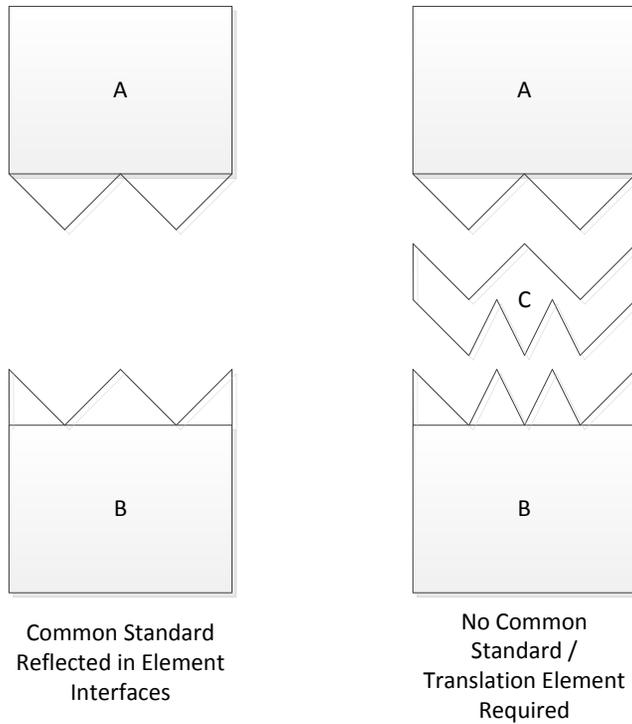
A standard may be defined as "... a construct that results from reasoned, collective choice and enables agreement on solutions of recurrent problems" (Tassely 2000). To address the ambiguity inherent in the term, it is necessary to detail the specifics of the standard under consideration (Jakobs 2005). In this section first we review what an open technology standard is and how it may be effectively characterized to make an

evaluation of its impact meaningful. We then review what theory predicts the general impact of the introduction of the standard will be, how that impact is likely to vary over time, and how we might assess it.

### **Nature and Characterization of an Open Technology Standard**

Industries are composed of constituent firms who generate classes of interdependent products (or, equivalently, artifacts for consumption) (Economides 1996; Nightingale 1978). These interacting products form complex systems, each of which may in turn be considered as a single superordinate (holistic) product or a collection of complementary products, depending upon the industry, the nature of the identity of the products being considered, and the degree to which the subordinate products are seen as integrated into a greater whole (Economides and Lehr 1995). For example, a product such as a car may be considered as a complex system composed of interacting automotive parts, each of those parts being subordinate products to the car. In contrast, a smartphone device, its case, and its applications may be more likely to be perceived as a complex system composed of complementary products.

Standards within an industry may fulfill a number of distinct functional roles (Krechmer 2000; Sherif 2001). In order for the subordinate elements of a complex system to successfully interoperate, they must either share a compatibility standard (reflected in the design of their interface points) for how that interaction can occur, or an additional translation interface (adapter) must be provided (David and Greenstein 1990; Economides 1996; Katz and Shapiro 1994). Here, interaction may be defined as the transfer of information or action from one element of the system to another. Compatibility standards specify the properties a product must have to successfully interact (Tassey 2000). Figure 5 shows a conceptual illustration of each approach.



**Figure 5: Common Standard vs. Translation Interface Layer**

To the extent that compatibility standards are defined across the element types and their iterative versions in a complex system (or superordinate product), a system may be described as having a higher degree of standardization (Tassely 2000). This may be conceptualized as a spectrum (Wacker and Treleven 1986). At the low end, a common standard for the interaction of two elements is only defined as needed for a given specific set of elements, without consideration for different versions or iterations of those elements, the future inclusion of additional elements, or the future need for additional functionality. At the high end, a common standard is defined for all the elements of a complex system, multiple versions of those elements, and future functionality. This spectrum is shown in Figure 6.



**Figure 6: Degree of Standardization**

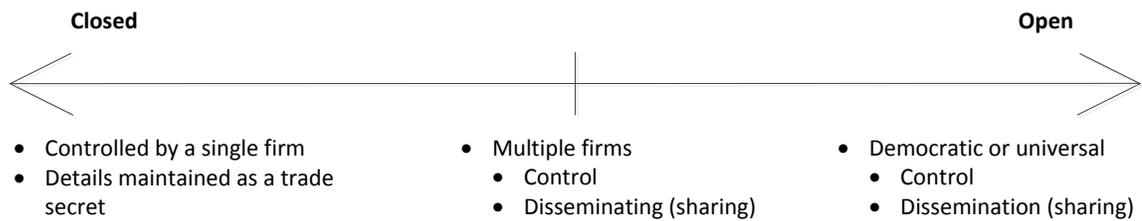
To be useful, the degree of standardization must be considered relative to a defined scope. I.e., one must consider what composition defines the complex system under consideration. The scope defined by a documented standard is often used for this purpose. For example, the universal serial bus (USB) standard describes a complex system that includes, among other things, a common standard for the interface of host and slave devices (e.g. a personal computer and a keyboard, respectively).<sup>19</sup> The USB standard addresses all the elements in its system, is robust to multiple versions or iterations of the elements of its system (e.g. personal computers and keyboards), and supports functionality for current and future elements, and may therefore be classified as having a high degree of standardization.

To the extent that common standards are maintained by and disseminated to broad representation across industry members, a standard may be referred to as “open” (West et al. 2007). Multiple dimensions to openness have been proposed relative to the specific processes involved (Krechmer 2006; West et al. 2007); however, for our purposes we

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<sup>19</sup> See <http://www.usb.org> for official documentation of the USB standard (Archived by WebCite® at <http://www.webcitation.org/6ZUG7hSN4>)

aggregate those measures into two dimensions: the ability to modify the standard (control), and the ability to use the standard (access). This may be conceptualized as a spectrum ranging from “Closed” to “Open”. In the ideal, an open standard is one in which the creation and maintenance of the standard is managed by representatives of all interested parties, and the details of the standard are freely available to those interested parties. In contrast and in the extreme, a closed standard is one in which the standard is managed by a single firm and the details of the standard are kept as a trade secret by that firm. This spectrum is shown in Figure 7.



**Figure 7: Degree of Openness**

We may therefore usefully characterize a standard by which industry or industries are relevant (or, equivalently, which product types or product families are relevant), the scope of the standard as defined by the standard, the functional role the standard plays, the degree of standardization, and the degree of openness. In this work we will be assessing the impact of the Future Airborne Capability Environment (FACE™) Open Technical Standard. This is a compatibility standard defining software interfaces for U.S. Defense Avionics systems. The standard is designed to support all the software systems in an aircraft across multiple versions of each element; therefore its design reflects a high degree of standardization relative to its prescribed scope. The standard is managed by a voluntary standard-setting organization (SSO), who coordinate a democratic consortium

of industry representatives and who ensures the uninhibited dissemination of the standard to all interested parties (Rysman and Simcoe 2008). The standard may therefore be classified as having a high degree of openness.

## **Impact of an Open Standard**

### What Changes

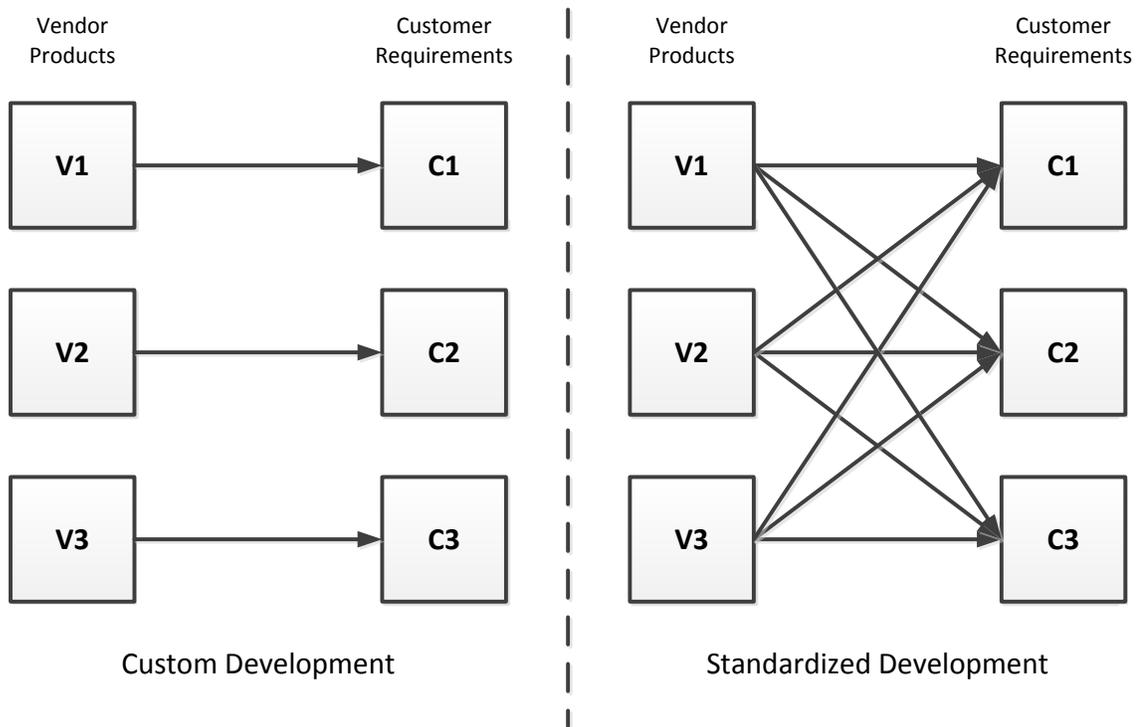
Open standards may affect a product's utility, price, and cost. In general, these effects apply to both the product elements (subordinate products) as well as the holistic product (superordinate product).

Open standards may increase the utility of products built by enabling an element built to the standard to have a greater number of potential applications (Katz and Shapiro 1994; Matutes and Regibeau 1988). In other words, products built to the standard will meet the requirements for more potential uses. For a subordinate product, this may mean that the element may be used in more superordinate products. For a superordinate product, this may mean that the element may be used for more completed applications.

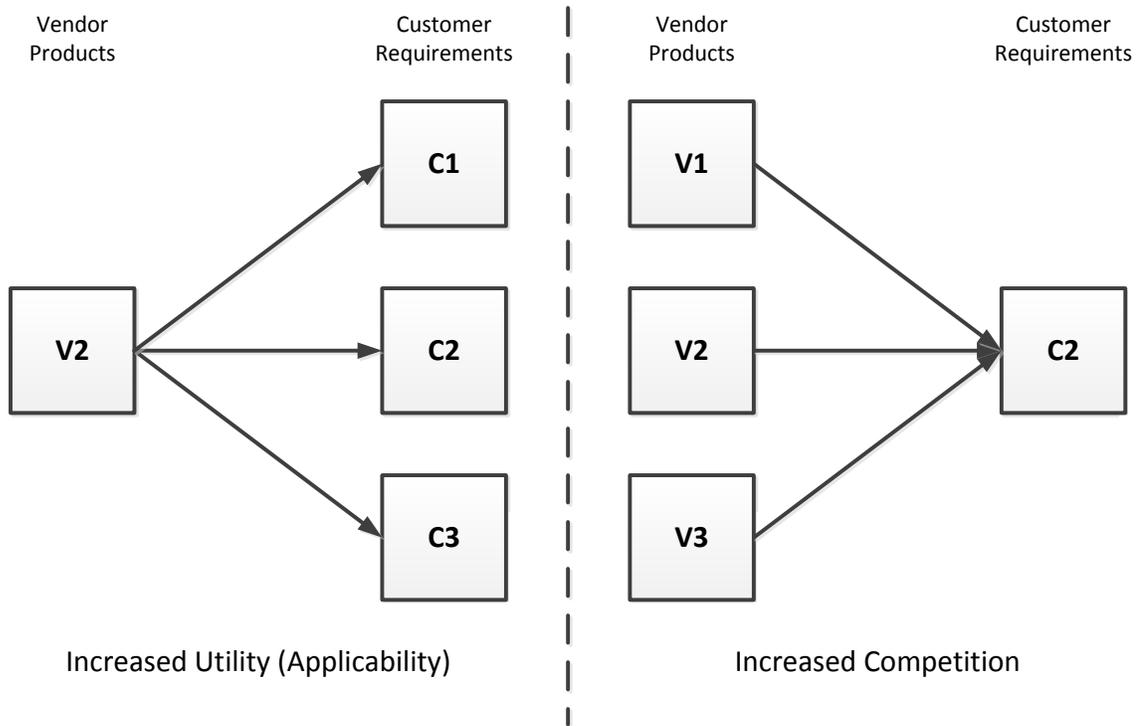
Open standards may decrease the price of products by increasing competition between suppliers (Matutes and Regibeau 1988). This reduced price results from two different mechanisms. First, increased competition pushes pricing from value based to cost based, with margins trending towards zero. Second, pricing pressure in turn pushes firms to reduce costs by seeking efficiencies and attempting to reduce costly inputs (such as labor).

Figure 8 shows a comparison between traditional custom development and standardized development. Under custom development, the each vendor's product offering may be uniquely suited to a given customer. Under standardized development,

vendor product offerings are likely to be suited to a wider range of customers. Figure 9 shows the effect of standardized development separately from the vendor and from the customer perspective, to highlight the two primary effects: increased utility and increased competition.



**Figure 8: Custom vs. Standards-based Development**



**Figure 9: Benefits of Standards-based Development**

Open standards may directly decrease the cost of building products by enabling the reuse of pre-existing knowledge artifacts and physical artifacts. The use of pre-existing knowledge artifacts reduces the necessary learning for a given element, provides a common base of knowledge for shared understanding and communication among team members, and may support the development of greater expertise than would accrue if relevant information were more ephemeral or circumstantial (Garud et al. 2009). The use of pre-existing physical artifacts may directly substitute for part of the cost of generating that physical artifact anew (Kindleberger 1983). In addition, the use of standards enables work to be performed in a parallel and distributed manner (Garud et al. 2009). These efficiencies are likely to occur across projects and products that share the standard. The degree of standardization and the degree of openness may increase utility and competition, as well as decrease costs (Tassey 2000).

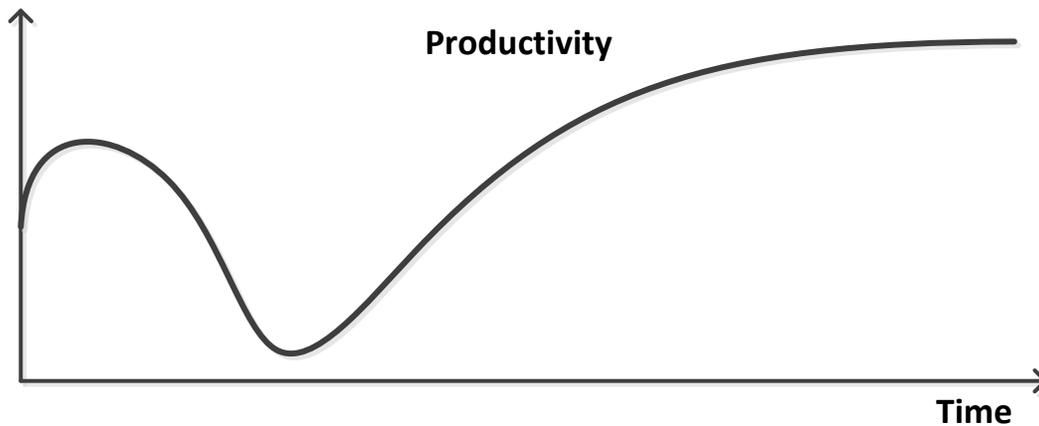
In the case of software development, the primary cost driver is the labor (project effort) required to create, tailor, and integrate software code (Endres and Rombach 2003). The version releases of products, as outputs, correspond to software development projects.

A large body of prior work relates software project factors to the effort required to create a software product (Jorgensen and Shepperd 2007). Therefore, by looking at the impact of change on software factors we can estimate not only how the change differentially affects the different parts of a project, we can also (in aggregate) see how the overall project effort (and thereby cost) is affected. The venerable Constructive Cost Model (COCOMO) is perhaps the most established tool for this type of project effort estimation, and is designed to be robust to a variety of software engineering project types (Boehm 1981; Boehm et al. 2000b). An extension, the Constructive Systems Engineering Cost Model (COSYSMO), is tailored to systems engineering projects (Valerdi 2005). While many firms use these tools with minimal alteration, it is not uncommon for firms to devise and calibrate their own versions of these tools using a comparable approach but with custom project descriptors and calibrated values (Boehm et al. 2000a).

#### How it changes with time

The process of adopting an open standard may be conceptually considered as a diffusion of an innovation, in the same manner as the adoption of a new technology or methodology (Rogers 1995). The two fundamental costs of adoption are the training of organizational members to use the standard, and the cost of adapting existing artifacts to be compliant with the standard. In addition, the benefits associated with adoption of the standard are likely to be proportional to the extent to which the adoption is completed.

Full benefits are only achieved after a sufficient period has occurred to allow user expertise and affected artifacts to mature. Given the additional upfront costs and delayed benefits of adoption, one should expect product development to suffer a cost premium in the short term before benefits are realized in the long term. This is consistent with the expectations of a learning curve or change management curve, as shown in Figure 10. In this figure the trough represents the full burden on the change, and the rising curve following the trough representing recovery and eventual exceedance.



**Figure 10: Change Management Curve**

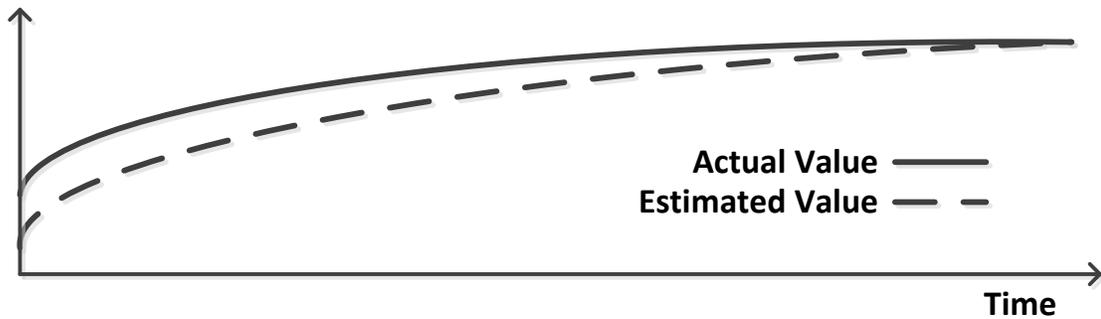
All change invokes a learning curve by those who experience the change (Argote 1999). In the case of the adoption of any new technology by a firm, this learning curve leads to reduced effectiveness in the processes the technology supports until sufficient experience is achieved. This initial reduction in performance is reflected in the time spent and therefore the cost to complete project tasks. The steady-state effectiveness achieved when learning plateaus is contingent upon the quality of the technology adopted relative to the process needs of the firm and the capabilities of those using it (Argote 1999). This

quality should be expected to increase as the platform is updated with time and problems are addressed and new features are added. Therefore we may anticipate that the performance from using a new open technology standard to begin at a lower state and to increase with time, and for the performance level of the initial and final state states, as well as the length of time necessary to get there, to vary relative to the characteristics of the firm.

#### How we assess it

Objective information is not always available. This may occur due to limitations in what information may be gathered about an event that has past, because some or all of the events impact lies in the future, or some combination of those two. In these cases forecasting techniques may be used to provide estimates based upon individual or group judgments, thereby leveraging the available conscious and tacit knowledge.

A prominent approach to forecasting is the Delphi method (Rowe and Wright 1999). This method uses a group of domain experts to iteratively build a consensus view of an otherwise unknown event. As such, the results of the Delphi method may reflect the best available estimate of an event when other data sources are not available. When forecasting is repeated, these estimates may be expected to attenuate with the actual values with time as more information becomes available. Figure 11 shows two hypothetical curves reflecting a series of estimated valued and a series of actual values. The gap between these curves should be expected to decrease with time.



**Figure 11: Attenuation of Estimation and Actual Values**

Since these results also reflect the perspective of domain-relevant experts, they may also be useful in informing others as to the beliefs of those experts and those whom they represent. This may consequently inform others as to the type of actions these experts and their constituencies are likely to take, and thereby suggest possible interventions to those actors to assist in achieving a desired outcome.

### **Context**

In this section we introduce our context, provide some general background, discuss why it is valuable, and discuss why it is an interesting backdrop for an open standard.

In this study we explore the impact of the introduction of an open technology standard on the U.S. defense avionics industry. Aircraft costs are now dominated by software development (e.g. more than 90% of the F35 aircraft's functions are managed by software), and these costs have continued to rise while defense spending faces

increasing budget pressure (Arena et al. 2008; Ferguson 2001).<sup>20</sup> The defense avionics industry is a multi-billion dollar concern composed of all the firms that supply hardware, software, and services for the construction and servicing of U.S. military aircraft.<sup>21</sup> This may occur through direct contract or sales, or through indirect supply through point of contact firms (e.g. through subcontracting).

A small number of large firms exist that are frequently used by the government as the primary contract holder, or “prime”. Primary contract holders are responsible for subcontracting and coordinating supply and service as needed for fulfillment of the contract, in addition to providing supply and services directly. Boeing and Lockheed Martin are two prominent examples of primes. A larger number of smaller and more specialized firms exist that service the prime-managed contracts.

Defense avionics contracts are characterized by high costs. These costs are commonly attributed to a lack of reuse of product that is perpetuated by a lack of competition and a lack of standardization. The impact of this lack of reuse is exacerbated by the high number of aircraft models and their variations that are presently in service. It is not uncommon for military aircraft to have a lifespan of 30-50 years, with continuous incremental model variations occurring over that time. In addition, models are often differentiated by customizations that are mission-type specific. For example, two

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<sup>20</sup> Also see this discussion by SEI of defense avionics software costs: <http://blog.sei.cmu.edu/post.cfm/the-growing-importance-of-sustaining-software-for-the-dod> (Archived by WebCite® at <http://www.webcitation.org/6ZDOZtuQR>)

<sup>21</sup> See <http://www.bga-aeroweb.com/Military-Aircraft.html> for budget details (Archived by WebCite® at <http://www.webcitation.org/6ZDQjK0d0>)

different branches of the military often have their own model variations of the same base aircraft. Each of these model variations creates opportunities for custom product development.

To address these concerns, a multi-branch initiative called FACE<sup>TM</sup> (Future Airborne Capability Environment) was formed to create an open technical standard for defense avionics software.<sup>22</sup> Software was made the focal point of this standard because it is increasingly recognized that software accounts for the majority of defense avionics project cost. While hardware costs have remained comparatively constant, software costs have continued to grow significantly as an increasing amount of the functional complexity of defense aircraft has shifted from the hardware to the software. This trend may be epitomized by modern aircraft such as the F-35, where the advanced functionality highlighted in its design, such as techniques for interpreting human movement and providing information through the heads up display, are clearly software and processing driven.<sup>23</sup> The FACE standard is recognized as having a high degree of standardization.

The government employed the Open Group, the standards setting organization (SSO) responsible for managing the venerable TOGAF<sup>24</sup> standard, to guide the creation and establishment of the FACE standard. As part of this process, the Open Group created

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<sup>22</sup> See <http://www.opengroup.org/face> for a detailed overview of the FACE open technical standard (Archived by WebCite® at <http://www.webcitation.org/6ZDR0bdQ5>)

<sup>23</sup> See <https://www.f35.com/about/life-cycle/software> for a discussion of how software powers the advanced capabilities of the F-35 (Archived by WebCite® at <http://www.webcitation.org/6ZXVBLKx8>)

<sup>24</sup> TOGAF is an acronym for The Open Group Architecture Framework, and refers to an industry standard enterprise architecture framework. See <http://www.opengroup.org/togaf/> for a detailed overview (Archived by WebCite® at <http://www.webcitation.org/6ZU7i8jR3>)

a consortium of government and industry representatives to work collectively to create the standard. As part of the consortium, two university engineering groups were contracted to do the technical work of prototyping the standard and supporting tools. Membership in the consortium is open to all interested parties, with firm representative roles in committees being determined diplomatically, and with public dissemination of all generated artifacts. Therefore, the standard is characterized as highly open.

At the time of the study, the consortium had completed version 1.0 of the standard and requests for products (RFPs) were beginning to be issued that required the use of the standard for solutions provided. Whether or not an RFP required the use of the standard was at the discretion of the office generating the RFP.

### **General Methodology & Data Collection**

In this study we seek to understand the impact of the introduction of an open technology standard on the defense avionics industry. We do this by assessing this impact on the software engineering project effort of both the overall industry and industry archetypes. This, in turn, required that we devise a way to evaluate the impact of the standard on project characteristics relative to both industry archetypes and project archetypes.

#### **Industry Archetypes**

A combination of interviews and consortium generated documentation were used to identify industry archetypes. This information was also used to generate an ecosystem model of the defense avionics industry to validate the identification and role of the industry archetypes used.

#### **Software Project Impact**

Objective information on projects prior to the instantiation of the standard was not available due to the high degree of secrecy practiced in the industry as well as government regulations regarding access to project data that are intended to protect industry members. To obtain the best available estimates of objective project impact, as well as to capture the consensus view and expectations of industry member experts, a Delphi study was conducted on consortium members as a four part series of surveys.

The Delphi study was structured to capture the estimated impact of the use of the standard on the effort associated with project factors. These project factors were drawn from established software cost estimation models built to generate effort estimates from project characteristics.

The literature suggests that potentially hundreds of factors can potentially affect software development costs (Demarco 1982). These can include a large number of potential factors from any of the following standard categories:

- Personnel factors: such as experience, skills and team size
- Project (process & tool) factors: such as programming language, methods and tools
- Product factors: such as complexity and application type
- Platform (Environment) factors: such as memory, storage and timing constraints

However, only a few of these drivers may significantly affect software costs within a given environment (Maxwell et al. 1999). It is not initially clear which cost drivers are relevant for avionics software, therefore in stage 1 we asked experts to

identify those drivers that are most relevant from a superset of drivers drawn from prior art and the literature.

Each survey asked for demographic information in addition to the target questions. Participants were asked to respond based upon typical defense avionics software engineering projects at their resident firm. Stages 1-3 were used to distill a short list of the more influential project factors, capture their relative contributions to project effort, estimate the impact of the standard on those contributions to effort, and compute an aggregate impact of the standard on project effort for a given scenario. Stage 4 was used to triangulate the aggregate impacts estimated in Stages 1-3 by directly capturing the estimated impact of the standard on the effort associated with the complete set of COCOMO factors and computing a second estimate of overall project impact.

## **Pre-Study**

### **Project Types**

The impact of the adoption of an open technology standard should be expected to vary based upon the type of development being performed, the maturity of the practices being used, and whether or not the system for which the software is being developed is, itself, conformant to the standard. Software development may generally be classified into either legacy system software development where development occurs with significant dependence upon existing code or new system software development where development occurs with relative autonomy. The maturity of the practices being used, both in general and relative to the standard if used, may be reflected by the timeframe of the project. Finally, in cases where software development has legacy code dependencies, it is useful to specify whether that legacy code is standards-based. Using these classifications, project effort may be considered for the following project types:

1. Non-standard legacy system in the short term
2. Non-standard legacy system in the long term
3. New system in the long term
4. Standard-based legacy system in the long term

This list of project types also embodies the assumptions 1.) that no new systems, which are frequently associated with new aircraft, will be built in the short term, 2.) that no standards-based systems will be available until the long term, and 3.) that a new system, by definition, has no significant code dependencies and so does not need to be specified as non-standard or standard.

### **Industry Archetypes**

To understand the impact of the standard on software development project effort it is useful to identify not only how project effort is impacted in aggregate for the industry but also how that impact varies by the type of the industry firm. While generic classifications are available, it is more useful to define types that are relevant and meaningful to the industry under consideration. To identify these types, we began by using documentation built collaboratively and vetted by the consortium's industry representatives as part of their effort to plan general business considerations of the standard's use with respect to their member firms.<sup>25</sup> The consortium identified three key firm archetypes in the defense avionics industry based upon the firm's primary role in the

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<sup>25</sup> See the FACE Business Guide 1.1 available at <https://www2.opengroup.org/ogsys/catalog/g115> (Archived by WebCite® at <http://www.webcitation.org/6ZAJDuLOZ>)

industry: software suppliers, avionics suppliers, and system integrators. Each of these types provides products and/or services to the defense avionics market, and may also participate in the civilian avionics or other markets. To better illustrate how these firms work together, we will use the metaphor of how the personal computer (PC) industry supports the servers in an IT back office.

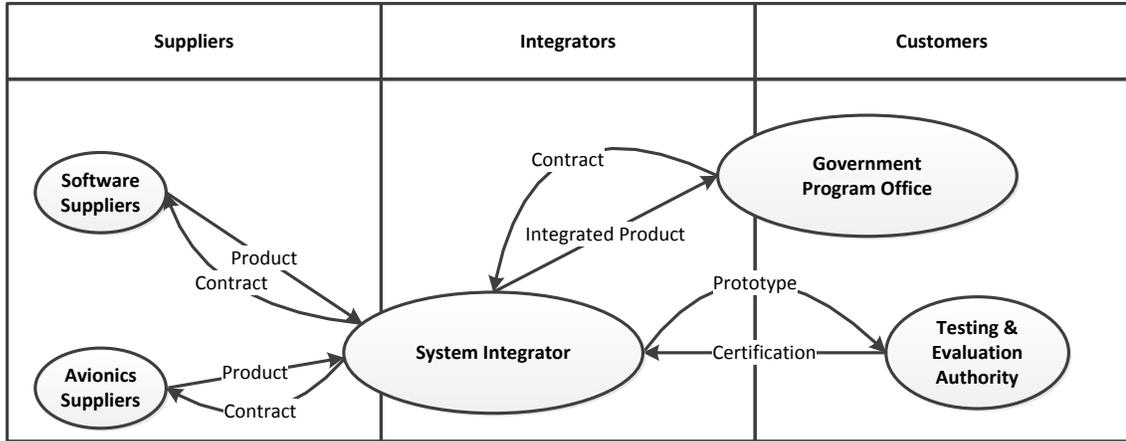
Software suppliers provide software products, including but not constrained to applications, operating systems, and middleware. Software provided may be custom built, tailored from existing products, or unchanged from existing stock products (also known as “Commercial off-the-shelf”, or COTS). In an IT back office, an equivalent would be software providers who provide the operating systems and server applications that run on the PC.

Avionics suppliers provide avionic subsystems. While some of these subsystems are hardware only, an increasing number of them will include software-based functionality. In an IT back office, an equivalent would be a PC hardware provider that provides computers, components, and peripherals, with the computers often being preconfigured with some combination of COTS and custom software.

System integrators assemble subcomponent hardware and software into completed aircraft systems. They generally serve as the primary contract holder and in doing so are responsible for meeting the overall system requirements of the customer and for coordinating those firms, typically suppliers, to whom they subcontract. In an IT back office, an equivalent would be an IT firm contracted to setup the servers in the back office and to ensure that the services provided are operating correctly and are

appropriately integrated (e.g. automated file backups are configured, file shares are network available, etc.).

Based upon these definitions and a series of discussions with consortium representatives, we developed a simplified ecosystem model depicting the roles of these firms in the industry. A business ecosystem is defined as “an economic community supported by a foundation of interacting organizations and individuals – the organisms of the business world” (Moore 1993). Based upon the longstanding work on natural ecosystems in anthropology and biology (Fitz et al. 1996; Grumbine 1994), a business ecosystem represents an analogical framework for considering a broad set of the loose network of agents who play a role in business outcomes (Iansiti and Levien 2004). These agents may include, but are not limited to, suppliers, distributors, outsourcing firms, makers of related products or services, trade associations, standards bodies, government institutions, and other interested parties (Iansiti and Levien 2004; Moore 1998). This model is shown in Figure 12. This model was circulated broadly for feedback to verify the validity of this method of classifying the roles of firms in the industry.



**Figure 12: Ecosystem Model Depicting the Software Supplier, Avionics Supplier, and System Integrator**

## Analysis & Results

### Stage 1

The purpose of stage 1 was to identify a subset of project factors that should account for the majority of project effort. We asked participants to rate the influence of each of 35 project factors on overall project effort for contemporary projects prior to the introduction of the standard.<sup>26</sup> This was asked with the assumption that the factors could be considered as linearly contributing to a project’s total effort, i.e. such that the project’s effort could be calculated by summing the effort independently associated with each project factor. These project factors were drawn from the current versions of the COCOMO and COSYSMO cost models (COCOMO.II.2000 and COSYSMO 2005, respectively), an internal military software cost model, and a review of the software cost

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<sup>26</sup> See appendix for details of the project factors considered.

estimation literature. For each factor participants were asked to indicate the extent to which the factor determined project effort by choosing from a six point Likert scale ranging from “Not at all” to “To a very large extent”. We asked participants to perform this rating twice: once for legacy system projects, and once for new system projects. 44 responses were received. We formed a rank ordered list for each of the two project types, and a subset of those project factors was chosen based upon the ranking of each factor and its consistency within emergent categories of project factors. These subsets are given in Table 4.

**Table 4: Subset of Project Factors by Project Type**

|    | <b>Legacy Development</b>                    |    | <b>New Development</b>                    |
|----|--|----|---|
| 1  | # and Diversity of Platforms/Installations   | 1  | Application Experience                    |
| 2  | Application Experience                       | 2  | Code Complexity                           |
| 3  | Code Complexity                              | 3  | Complexity of Integration                 |
| 4  | Complexity of Integration                    | 4  | Complexity and Extent of Testing Required |
| 5  | Complexity of Migrating from Legacy Platform | 5  | Development Schedule Constraints          |
| 6  | Complexity and Extent of Testing Required    | 6  | Development Specification Constraints     |
| 7  | Development Schedule Constraints             | 7  | Product Complexity                        |
| 8  | Product Type (e.g., Mission Critical)        | 8  | Product Type (e.g., Mission Critical)     |
| 9  | Required Software Reliability                | 9  | Requirements Understanding                |
| 10 | Requirements Understanding                   | 10 | Requirements Volatility                   |
| 11 | Requirements Volatility                      | 11 | Technology Maturity                       |
| 12 | Similarity to Previous Products              |    |   |

For legacy development projects, the most influential factors tended to relate to complexity (testing, integration, and code), requirements (volatility, understanding), product type, development specifications, # & diversity of platforms, required software reliability and application experience. For new development projects, the most influential factors tended to relate to product factors (complexity, type), complexity (testing,

integration, and code), requirements (volatility, understanding), schedule, technology maturity, and application experience.

## Stage 2

While the first survey provided a relative rank ordering of the effort contributions of the subset of project factors, it did not provide the comparative contribution of each of those factors to project effort. To determine the relative contribution of each project factor in a subset, we asked participants to perform a series of pair-wise comparisons to establish (calibrate) specific relative weightings for each project factor’s contribution. This was done by using an Analytical Hierarchical Process (AHP) structured survey. The AHP questions are composed of a series of pairwise comparisons between each possible paired combination of project factors for each of the subsets identified in stage 1. Each participant rates one factor’s influence relative to another on a 7-point Likert scale ranging from “very much less important than” to “very much more important than” for each of two scenarios. AHP provides a comprehensive and rational framework for structuring decision making (Saaty 1980; Saaty 1990), and as such provides an established method for determining the contributions of project factors in software cost estimation (Finnie et al. 1993; Lee 1993). An example of an AHP pairwise comparison is given in Figure 13.

| Similarity to Previous Products is ...     |                               |                          |                              |                       |                              |                          |                               |
|--|-------------------------------|--------------------------|------------------------------|-----------------------|------------------------------|--------------------------|-------------------------------|
|  | very much less important than | much less important than | somewhat less important than | equally important to  | somewhat more important than | much more important than | very much more important than |
| # and Diversity of Platforms/Installations | <input type="radio"/>         | <input type="radio"/>    | <input type="radio"/>        | <input type="radio"/> | <input type="radio"/>        | <input type="radio"/>    | <input type="radio"/>         |

**Figure 13: Example of an AHP Pairwise Comparison between Two Project Factors**

We coded individual participant responses from 1/7 to 7. We then averaged these responses for each comparison, and calculated a geometric mean for each project factor from the averaged comparison scores relative to that factor. These geometric means were then normalized by dividing by their total to provide the final granular linear project factor weightings shown in Table 5. See appendix for response coding and the AHP response matrix.

**Table 5: Project Factor Contributions of Project Effort**

| Legacy Development Projects |  |                              | New Development Projects |   |                              |
|-----------------------------|--|------------------------------|--------------------------|---|------------------------------|
|                             | Project Factors                              | Percentage of Project Effort |                          | Project Factors                           | Percentage of Project Effort |
| 1                           | # and Diversity of Platforms/Installations   | 4.8%                         | 1                        | Application Experience                    | 5.0%                         |
| 2                           | Application Experience                       | 6.1%                         | 2                        | Code Complexity                           | 6.3%                         |
| 3                           | Code Complexity                              | 6.9%                         | 3                        | Complexity of Integration                 | 9.1%                         |
| 4                           | Complexity of Integration                    | 9.0%                         | 4                        | Complexity and Extent of Testing Required | 9.7%                         |
| 5                           | Complexity of Migrating from Legacy Platform | 7.3%                         | 5                        | Development Schedule Constraints          | 7.3%                         |
| 6                           | Complexity and Extent of Testing Required    | 9.1%                         | 6                        | Development Specification Constraints     | 5.6%                         |
| 7                           | Development Schedule Constraints             | 7.8%                         | 7                        | Product Complexity                        | 9.1%                         |
| 8                           | Product Type (e.g., Mission Critical)        | 6.9%                         | 8                        | Product Type (e.g., Mission Critical)     | 6.9%                         |
| 9                           | Required Software Reliability                | 9.1%                         | 9                        | Requirements Understanding                | 13.1%                        |
| 10                          | Requirements Understanding                   | 10.9%                        | 10                       | Requirements Volatility                   | 16.0%                        |
| 11                          | Requirements Volatility                      | 12.9%                        | 11                       | Technology Maturity                       | 12.0%                        |
| 12                          | Similarity to Previous Products              | 9.1%                         | 100.00%                  |   |                              |
| 100%                        |  |                              |                          |   |                              |

### Stage 3

In Stage 1 and Stage 2 we established a subset of project factors that determine project effort and calibrated for their relative contributions. In Stage 3 we asked

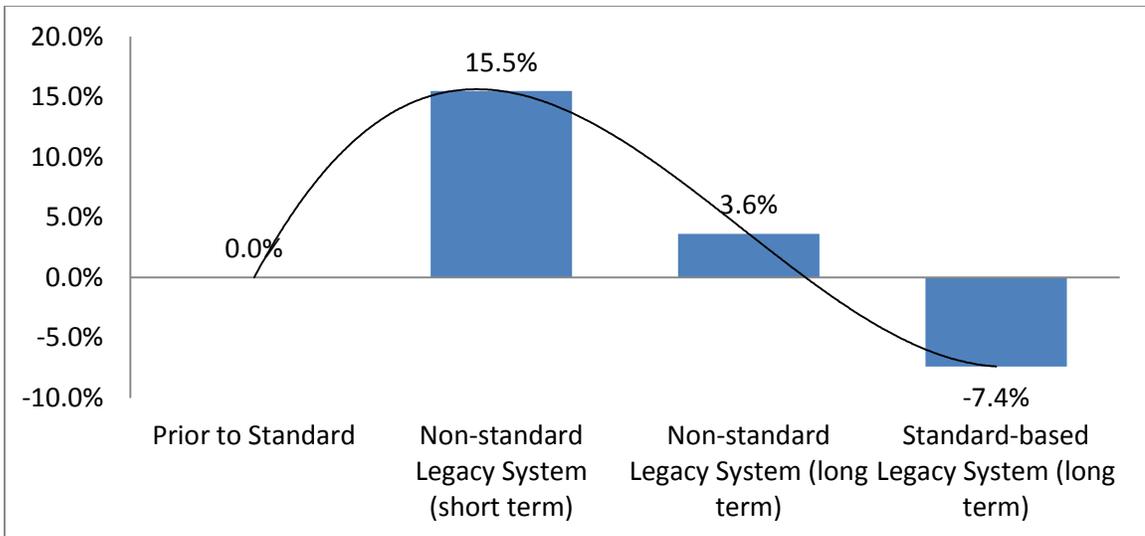
participants to estimate how much the effort associated with each project factor would change with the use of the standard. Given that we were now considering the future impact of the standard, the type of projects considered needed to be expanded to specify an additional possible beginning state of the system for which development was occurring and add the time frame during which the project would occur. For stage 3 we identified four different project types to define the impact of the introduction of the standard. We define these as follows:

Standard-based development for a ..

1. Non-standard legacy system in the short term
2. Non-standard legacy system in the long term
3. New system in the long term
4. Standard-based legacy system in the long term

The first two project types were chosen because standard-based development for existing non-standard legacy systems will define the majority of initial projects and will continue to define many projects into the future given the number of legacy systems in use, their longevity in the field, and the rate at which they are updated. The third project type was chosen because the industry does not anticipate significant development for new systems in the short term. Finally, the fourth project type was chosen because 1.) it represents a potential boundary condition for the impact of the standard and 2.) given the duration of projects, including the types of projects that would occur to instantiate a standards-based system for future use, it is likely that standards-based systems will not exist for some time.

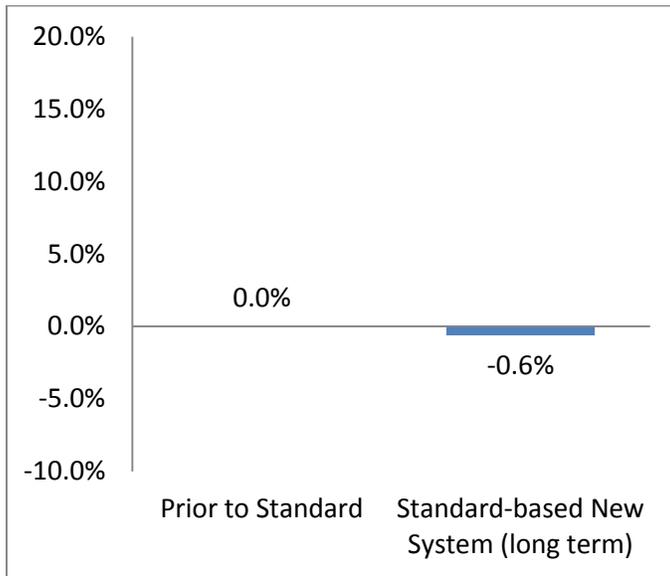
For each of these project types, participants estimated the percentage change in the effort associated with each project factor. For each project type the estimated percentage change for each project factor was averaged across respondents, multiplied by the percentage of project effort previously calculated for that project factor, and summed to form an aggregate estimated change in project effort for the given project type. For Project types 1, 2, and 4 the subset of project factors for legacy development were used. For project type 3 the subset of project factors for new development were used. 60 responses were received. Figure 14 shows the estimated changes to project effort for each legacy system project type. Figure 15 shows the estimated change to project effort for a new system project.



**Figure 14: Percentage Change in Legacy System Project Effort from Standard Use**

In short term, most development standard-based development will be for existing defense avionics systems. Participants anticipate a significant premium (15.49%) for what participant feedback suggests will likely be their first project using the standard. This is consistent with learning curve and change management expectations that

productivity will be dampened initially as new processes are learned and matured. This premium is also consistent with the expectation that additional overhead may be required to learn to develop to the standard, as well as to interface with, and in some cases update or convert, non-standard systems.



**Figure 15: Percentage Change in New System Project Effort from Standard Use**

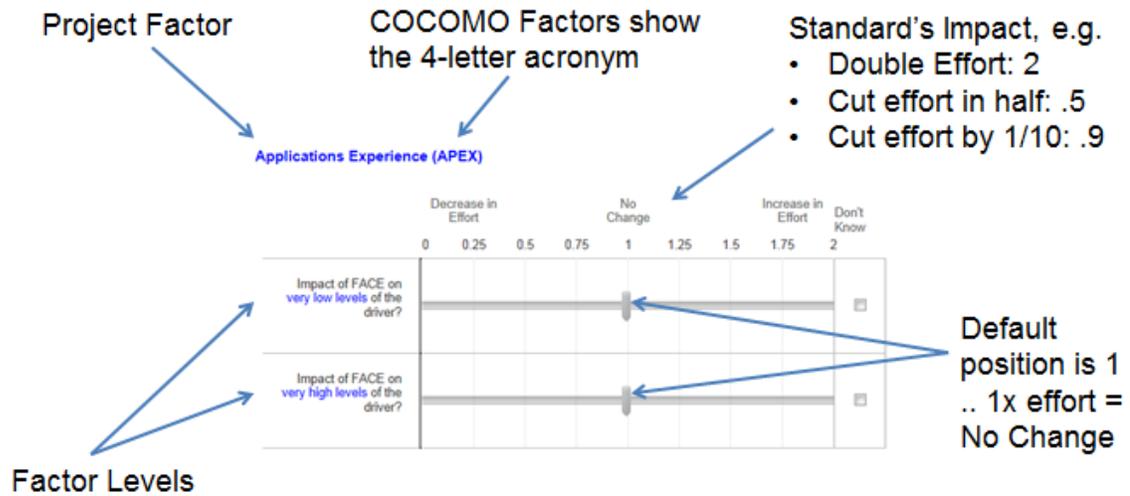
In the long-term, we expect processes to mature and so some of the efficiencies in learning and coordination to be realized, however, participants anticipate that those efficiencies will not be sufficient to overcome the overhead of working with non-compliant legacy systems (3.63%). However, once unencumbered by the need to address non-compliant systems, these efficiencies will allow new system development to receive some benefit (-.57%). Finally, significant effort savings are anticipated for systems that are standard-compliant (-7.38%).

#### **Stage 4**

In stages 1-3 we estimated the impact of the use of a standard on project effort by distilling a short-list of highly influential project factors, estimating their relative

contribution to overall effort, forecasting the impact of using the standard on those contributions, and summing those individual weighted impacts to form an overall measure of the change in project effort. In stage 4 we attempted to triangulate this measure by forecasting effort using a significantly different approach. To the extent that the results are comparable, this should provide validation of the results as effective measures of expert judgment by diminishing the potential presence of anomalies in approach or interpretation.

In stage 4 we asked participants to estimate the change in effort associated with each of a complete set of the COCOMO project factors known as cost drivers. However, instead of estimating the impact at the average or typical level of effort for a given project factor, we asked participants to estimate the impact twice: once for the minimum level of the project factor, and once for the maximum level of the project factor. For example, Application Experience is a COCOMO project factor that was present in Stages 1-3 and in Stage 4, and refers to the amount of effort associated with having developers of varying levels of experience with the application on the project team. In Stages 1-3, we asked participants to estimate the impact of the standard on the effort for that project factors associated with a typical or average case. In Stage 4, we asked participants to respond twice, once for a minimum level of Application Experience and once for a maximum level of Application Experience. In addition, in contrast to Stage 3 where we asked for a percentage change in Stage 4 participants were asked to estimate the proportionate change (e.g. 1.2x instead of 120%) in the effort associated with each of the project factors. An example of the question format is shown in Figure 16.



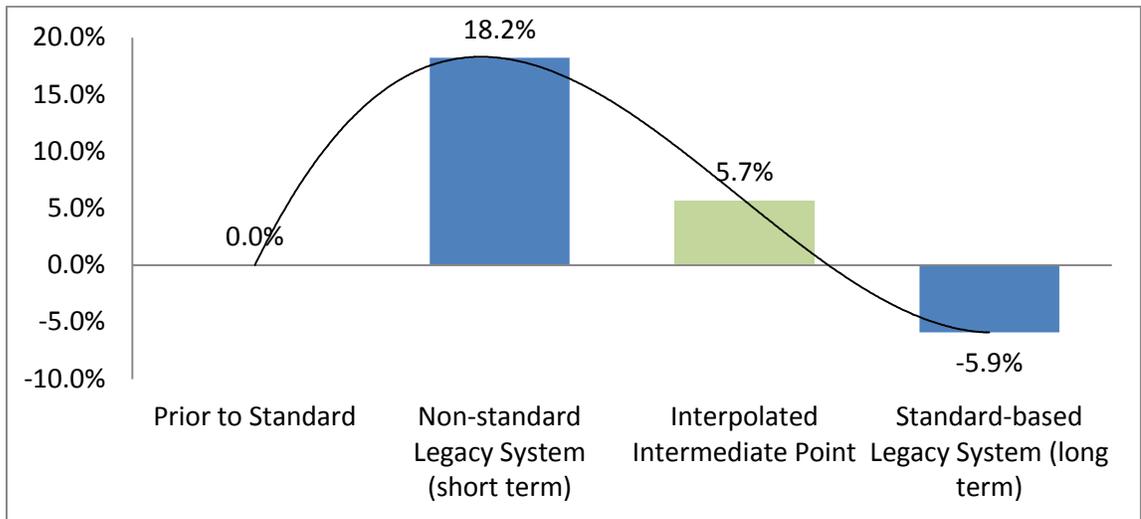
**Figure 16: Example of Stage 4 Question Format**

Given the length of the instrument and the desire to validate rather than recreate the earlier results, we measured the impact of the standard for three project types, omitting development for non-standard legacy systems in the long term:

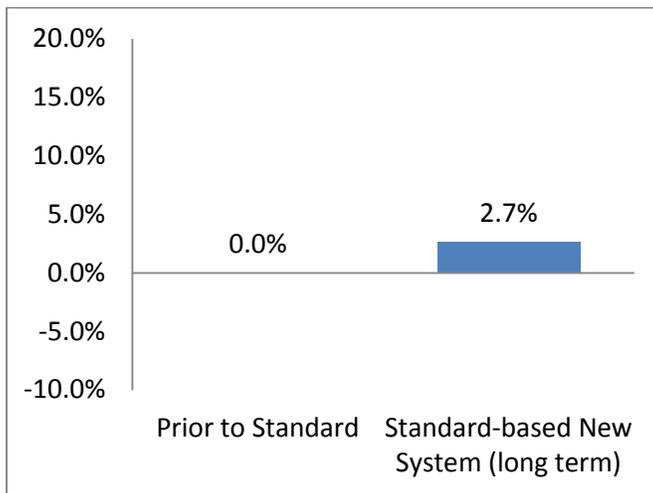
Standard-based development for a ..

1. Non-standard legacy system in the short term
2. New system in the long term
3. Standard-based legacy system in the long term

47 responses to stage 4 were received. The impact at the nominal value was then interpolated based on the average respondent minimum and average respondent maximum value, and those impacts were averaged across all of the project factors for a given project type to arrive at an overall forecast of the impact of the standard on project effort. The results for legacy system projects are shown in Figure 17. For comparison with the results of earlier stages, an intermediate point was interpolated between non-standard legacy systems in the short-term and standard-based systems in the long-term. The results for new system projects are shown in Figure 18.



**Figure 17: Percentage Change in Legacy System Project Effort from Standard Use**



**Figure 18: Percentage Change in New System Project Effort from Standard Use**

In comparing the results from Stages 1-3 and Stage 4 we can see that they are different but that the pattern appears consistent. Stage 4 suggests a higher premium for the use of the standard in the short term and a reduced effort reduction in the long term, however, given the nature of the estimation and forecast used variations of a few percentage points are likely not significant.

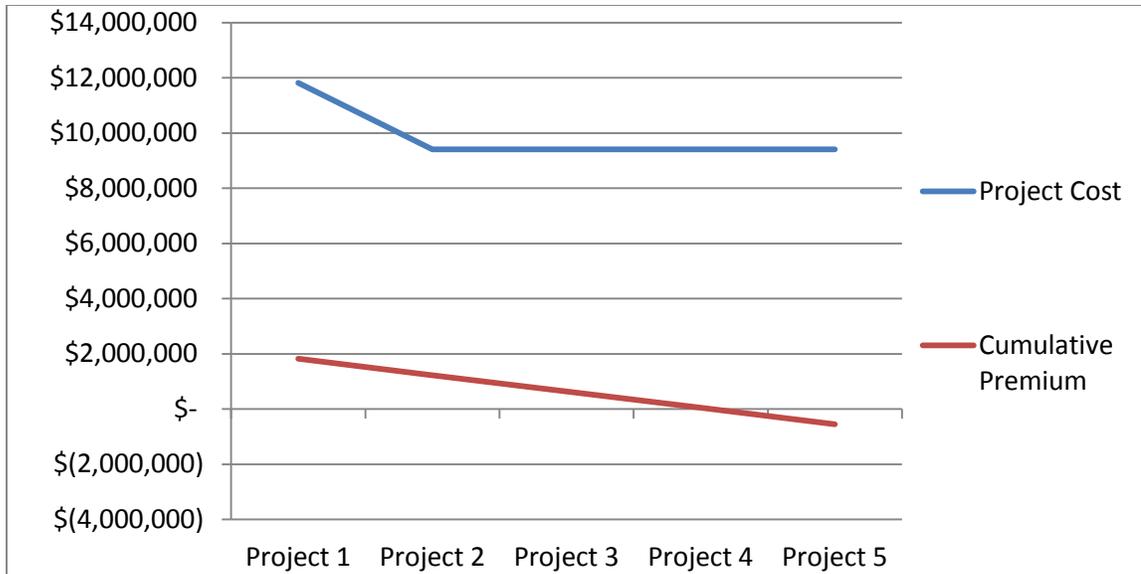
## Return on Investment

In the course of the study, each measure of the impact of the standard on project effort was assessed for projects of comparable size and scope. Since projects that use the standard for the first time leave the system standard-based upon completion, the return on investment for the standard may be calculated by considering the premium for the first project relative to savings for each successive project to find the project at which break even occurs. This initial premium is dependent upon the type of first project to implement the standard (Non-standard Legacy System (short-term), Non-standard Legacy System (long-term), or Standard-based New System (long-term)). Figure 19 shows the per project cost and cumulative cost premium of using the standard over time for a succession of projects following an initial short-term legacy system project. We are able to apply the percentage premiums to project costs because project effort directly translates into labor dollars.<sup>27</sup> \$10,000,000 is used as an order of magnitude appropriate placeholder value for the cost of the project prior to the standard to illustrate this impact in dollar terms.<sup>28</sup> The values estimated in stage 4 are used (18.2%, -5.9%). The breakeven point is exceeded with project 5. This represents the worst case scenario.

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<sup>27</sup> Project Cost = Effort (person hours) \* Labor Rate (\$/hour)

<sup>28</sup> Industry feedback suggests early stage project cost estimates are typically given in millions, with ten million being a mid-range value.



**Figure 19: Breakeven Project for Standard-based Short-term Legacy Project**

Table 6 shows the per project dollar costs and breakeven project for each type of first project. This highlights two key expectations. First, that a breakeven point is inevitable. Second, that if the developer and tools are sufficiently mature for the first project, savings are expected to accrue with the second project. This suggests that those firms with experience building to the standard may have a significant advantage for future projects. However, unless the government recognizes the initial premium as appropriate, that firm could be unduly penalized for the additional overhead of the first project using the standard, possibly putting the firm at a disadvantage when competing for the next project based on perceived bad performance for the previous project.

**Table 6: Breakeven by First Project Type**

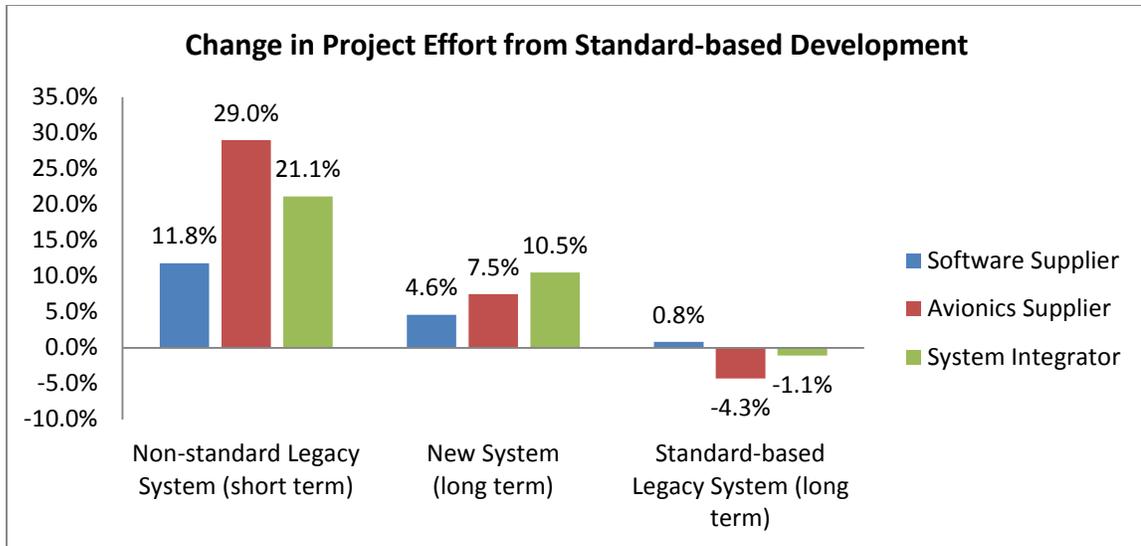
|           | Non-standard Legacy System (short-term) |                    | Non-standard Legacy System (long-term) |                    | Standard-based New System (long-term) |                    |
|-----------|---|--------------------|--|--------------------|---------------------------------------|--------------------|
|           | Project Cost                            | Cumulative Premium | Project Cost                           | Cumulative Premium | Project Cost                          | Cumulative Premium |
| Project 1 | \$ 11,821,438                           | \$ 1,821,438       | \$ 10,567,641                          | \$ 567,641         | \$ 10,269,289                         | \$ 269,289         |
| Project 2 | \$ 9,408,476                            | \$ 1,229,915       | \$ 9,408,476                           | \$ (23,883)        | \$ 9,408,476                          | \$ (322,234)       |
| Project 3 | \$ 9,408,476                            | \$ 638,391         | \$ 9,408,476                           | \$ (615,406)       | \$ 9,408,476                          | \$ (913,758)       |
| Project 4 | \$ 9,408,476                            | \$ 46,867          | \$ 9,408,476                           | \$ (1,206,930)     | \$ 9,408,476                          | \$ (1,505,282)     |
| Project 5 | \$ 9,408,476                            | \$ (544,656)       | \$ 9,408,476                           | \$ (1,798,454)     | \$ 9,408,476                          | \$ (2,096,805)     |

**Impact by Industry Archetypes**

Due to the changing demographic composition from stages 1-3 and the compounding nature of their calculations, it is problematic to draw inferences as to an archetypal division of their overall estimate. Stage 4, however, provides sufficient discrimination to allow us to propose the following division of the aggregate impact of use of the standard by archetype. Figure 20 shows a breakdown of the impact of the standard by archetype, and is derived from a subset of the respondent data as not all respondents were affiliated with one of these three firm types.<sup>29</sup>

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<sup>29</sup> Results based upon 16 system integrators, 6 avionics suppliers, and 11 software suppliers.



**Figure 20: Change in Project Effort by Industry Archetype**

Software suppliers would appear to anticipate the least premium in developing for non-standard legacy systems in the short term and new systems in the long term, however, they also anticipate attenuating to a state of no significant cost or benefit from the standard in the long term. This may suggest the belief that their current practices and processes are sufficiently mature such that both the initial disruptions and long term benefits of a standard will be minimized. This may also reflect a software supplier expectation that the standard will primarily affect interfaces at the boundary of what they build, such that they will incur the overhead of meeting the standard but, since they will not be responsible for interfacing across this boundary, they will not capture the full benefit of the standard.

Avionics suppliers, who straddle the line between hardware and software, anticipate the highest initial effort premium initially with development for non-standard legacy systems. This premium reduces significantly for new development, and becomes the largest estimated reduction in effort in the long term when existing systems are

standards-based. This may reflect a higher level of disruption given the number of interfaces involved, but also the highest level of benefit potential as those interfaces become standardized. Given the avionics suppliers role in both hardware and software, they may expect to need to accommodate a higher variety of interfaces from project to project.

System integrators also experience a higher than average premium initially for the non-standard legacy upgrades, with less reduction for new system development and a negligible benefit for development for a standards-based legacy system. System integrators tend to service as both software supplier and avionics supplier to an extent, in addition to being responsible for the integration of components. The amount of integration work may not change significantly initially, making the impact to the system integrator, initially, a compromise between the role of software supplier and avionics supplier. However, over time as the standard is adopted and greater modularity is achieved, the overhead of coordinating the integration of an increased number of modular elements may mitigate the potential benefits seen.

### **Discussion**

The U.S. defense avionics industry is a multi-billion dollar concern whose performance has broad implications for society. Given the importance of context specific influences, we have attempted to build a rich characterization of the standard being introduced as well as the industry being affected. Recognizing that defense avionics costs are increasingly determined by software, we explore the impact and implications of the adoption of an open technology standard on software development project effort.

Given the long lead times of defense avionics projects and the protectionist policies in places for industry members, empirical data relating to the impact of the adoption of the standard could not be available at the time of the study and could well not be available in the future. To address this we developed a method of forecasting the impact of an open technology standard on an industry's software development project effort by using a combination of software cost models, Delphi method, and AHP to leverage expert knowledge to generate estimates. This approach is readily adaptable to other types of change that a firm may experience by substituting other project cost estimation models for the software cost models used.

The results suggest that, consistent with expectations, in aggregate respondents anticipate an initial premium that reduces with time as developers, practices, and artifacts mature. This premium is primarily applied during the first project where the standardization is implemented for the system. In cases where the conversion occurs before sufficient maturity has been attained, the additional upfront costs may not be fully mitigated until the fourth subsequent project. Although this is a worst case scenario, expert feedback suggests that many more than five projects should occur within a lifetime allowing breakeven to be reached on each aircraft. In cases where the conversion occurs after sufficient maturity, costs are mitigated by the second project. Given the assumption that vendors will service multiple aircraft models, thereby effectively porting their expertise, we may assume that the average breakeven will be between these periods. The difference between first and second project suggests that project experience with the standard may be very valuable, and if recognized could give experienced firms a competitive edge and could greatly inform project estimates and expectations for contract

bidding. However, if the initial premium expected for developing to the standard is not recognized as appropriate, a firm that should otherwise have a competitive advantage may actually be penalized for poor performance and disadvantaged from future projects to the detriment of the firm and the government as a customer.

We also identify industry archetypes and separate the impact of the adoption of the standard by archetype. We find that software suppliers anticipate the least impact, suffering the least initial premium and enjoying no significant long term benefit. This may reflect their belief that their practices are sufficiently mature so as to nullify reuse-based benefits, or their expectation that the standard will primarily affect interfaces at the boundaries rather than internals of their products. Avionics suppliers anticipate the greatest initial premium and greatest benefit, possibly reflecting the variety of hardware and software interfaces they need to accommodate. Finally, system integrators are positioned between software suppliers and avionics suppliers with a relatively high initial premium and a relatively low final benefit. This likely reflects both the system integrators tendency to act as both software supplier and avionics supplier, as well as the anticipated increased overhead of assembling small modular components from a greater number of suppliers (Matutes and Regibeau 1988).

This work has strong implications for both research and practice. For research, we provide needed validation and quantification of the conceptually anticipated effects, including the learning curve orientation, of the adoption of an open technology standard. For practice, we provide a best estimate of the impact of the adoption of an open technology standard and suggest factors that may alter its effects. And for both research

and practice, we provide a method for forecasting the effect of major technology changes on both individual firms and entire industries.

### **Future Work**

The effects of the defense avionics industry's adoption of the standard will continue to unfold for some time. As archival data becomes available, empirical testing of the forecasts from this study would serve to further enrich our understanding both of the phenomena itself and of the relative accuracy of the forecasts and the extent to which expert opinions diverged. Given the U.S. government's traditionally limited access to industry firm project data, it may be best to partner directly with industry members, accepting that doing so may limit scope. Given the competitiveness and privacy concerns inherent in the industry, member firms will likely limit the researcher's ability to work with multiple firms.

### **Limitations**

One limitation of this study is that we are unable to succinctly identify the size of the industry or characterize it in such a way so as to determine the representativeness of the participants in the study. However, given that the industry being studied is defined by their relationship with the U.S. government's defense agencies who are actively engaged in the consortium, we believe that the type of relationship those government agencies have with their vendor constituency should be reflected in the participation seen in the consortium, making this group a de facto representative set.

## APPENDIX A: FOR CHAPTER 2, ANALYSIS OF TIME SPENT IN THE VIRTUAL WORLD COMMUNITY

We replicated our social bond analysis using variables that measure how long members spent using the virtual world community. We created the following variables to measure how much time each member spent in the virtual world community in the first seven days after registration (we varied the window size for robustness and results are consistent): *Minutes Online* (the number of minutes the member spent in the virtual world), *Number of Logins* (the number of distinct times the member logged in), *Number of Days Visited* (the number of distinct days on which the member logged in), and *Logins per Day* ( $Number\ of\ Logins / Number\ of\ Days\ Visited$ ). We used each of these for robustness, as they have slightly different interpretations. For example, a downward trend in *Number of Logins* could correspond to a reduction in use or to a shift to longer session times. Table 7 shows descriptive statistics.

**Table 7: Dependent Variables for Time Using the Virtual World Community**

|                          | Median | Mean  | Std. Dev. | Min. | Max.     |
|--------------------------|--------|-------|-----------|------|----------|
| Dependent Variables      |        |       |           |      |          |
| - Minutes Online         | 5.28   | 15.13 | 44.67     | 0    | 2,477.13 |
| - Number of Logins       | 2      | 4.25  | 7.40      | 0    | 191      |
| - Number of Days Visited | 1      | 1.72  | 1.39      | 0    | 7        |
| - Logins per Day         | 1      | 1.97  | 1.71      | 0    | 67       |
| Observations             | 75648  |       |           |      |          |

See text for variable definitions.

We used t-tests for each of our dependent variables to determine whether there is a difference between those members who are Facebook connected and those who are not. Table 8 suggests that Facebook connected members spend less time, on average, than

those members who are not connected to Facebook.<sup>30</sup> Facebook connected members spend approximately 1.6 fewer minutes (a 10.7% reduction) in the virtual world, log in 0.81 fewer times (an 18.7% reduction), visit 0.18 fewer days (a 10.3% reduction), and log in 0.13 fewer times per day (a 6.6% reduction). Each of these differences is statistically significant at  $p < 0.01$ , and the percentage reduction figures illustrate their practical significance. We also used regression to verify that these differences were robust to the inclusion of demographic and temporal factors. As shown in Table 9, the differences are robust and similar in magnitude to those shown in the t-tests. We also replicated the robustness checks discussed in our earlier analysis with the measures of time spent using the virtual world community. Results are consistent with those reported here.

**Table 8: T-Test Results: Time Spent In the Virtual World Community**

|                          | Mean for<br>members<br>who are<br>Facebook<br>Connected | Mean for<br>members<br>who are<br>Not<br>Facebook<br>Connected | Difference | %<br>Reduction | t      | p    |
|--------------------------|---|--|------------|----------------|--------|------|
| Dependent Variables      |   |  |            |                |        |      |
| - Minutes Online         | 13.65   | 15.28  | -1.63      | 10.7%          | -2.91  | 0.00 |
| - Number of Logins       | 3.52  | 4.33   | -0.81      | 18.7%          | -8.72  | 0.00 |
| - Number of Days Visited | 1.56  | 1.74   | -0.18      | 10.3%          | -10.49 | 0.00 |
| - Logins per Day         | 1.84  | 1.98   | -0.13      | 6.6%           | -6.18  | 0.00 |
| Observations             | 75648   |  |            |                |        |      |

All statistics are rounded to two digits.

<sup>30</sup> We also compared the dependent variables across the two user groups via Wilcoxon (Mann-Whitney) rank-sum tests. Results are consistent.

**Table 9: Regression Results: Time Spent In the Virtual World Community**

|                                  | Negative Binomial Regression |                              |                      |                              |                        |                              | OLS                               |
|----------------------------------|------------------------------|------------------------------|----------------------|------------------------------|------------------------|------------------------------|-----------------------------------|
|                                  | Minutes Online               |                              | Number of Logins     |                              | Number of Days Visited |                              | Logins per Day                    |
|                                  | Coefficient Estimate         | Marginal Effect <sup>a</sup> | Coefficient Estimate | Marginal Effect <sup>a</sup> | Coefficient Estimate   | Marginal Effect <sup>a</sup> | Coefficient Estimate <sup>b</sup> |
| Facebook Connected               | -0.119***<br>(0.021)         | -1.739***<br>(0.307)         | -0.208***<br>(0.015) | -0.867***<br>(0.061)         | -0.109***<br>(0.010)   | -0.187***<br>(0.018)         | -0.136***<br>(0.022)              |
| Female                           | 0.172***<br>(0.012)          | 2.518***<br>(0.180)          | 0.091***<br>(0.008)  | 0.381***<br>(0.035)          | 0.068***<br>(0.006)    | 0.118***<br>(0.010)          | 0.086***<br>(0.013)               |
| Age 18-24                        | 0.004<br>(0.014)             | 0.054<br>(0.202)             | -0.059***<br>(0.009) | -0.247***<br>(0.040)         | -0.024***<br>(0.007)   | -0.041***<br>(0.011)         | -0.066***<br>(0.014)              |
| Age 25-34                        | 0.125***<br>(0.020)          | 1.823***<br>(0.294)          | -0.031**<br>(0.014)  | -0.131**<br>(0.058)          | 0.005<br>(0.009)       | 0.009<br>(0.016)             | -0.077***<br>(0.021)              |
| Age 35-44                        | 0.225***<br>(0.028)          | 3.299***<br>(0.408)          | 0.019<br>(0.019)     | 0.080<br>(0.080)             | 0.043***<br>(0.013)    | 0.074***<br>(0.022)          | -0.065**<br>(0.029)               |
| Age 45-54                        | 0.344***<br>(0.040)          | 5.041***<br>(0.588)          | 0.029<br>(0.028)     | 0.123<br>(0.115)             | 0.071***<br>(0.018)    | 0.122***<br>(0.032)          | -0.156***<br>(0.042)              |
| Age 55-64                        | 0.073<br>(0.063)             | 1.067<br>(0.923)             | 0.132***<br>(0.043)  | 0.553***<br>(0.180)          | 0.081***<br>(0.029)    | 0.139***<br>(0.050)          | 0.026<br>(0.066)                  |
| Age 65+                          | -0.056<br>(0.064)            | -0.816<br>(0.933)            | 0.079*<br>(0.044)    | 0.330*<br>(0.182)            | 0.017<br>(0.030)       | 0.028<br>(0.052)             | 0.125*<br>(0.067)                 |
| Constant <sup>c</sup>            | 2.347***<br>(0.112)          |                              | 1.395***<br>(0.078)  |                              | 0.487***<br>(0.054)    |                              | 1.894***<br>(0.119)               |
| Fixed effects for Day Registered | Included                     |                              | Included             |                              | Included               |                              | Included                          |
| Observations                     | 75648                        | 75648                        | 75648                | 75648                        | 75648                  | 75648                        | 73901 <sup>d</sup>                |
| Log Likelihood                   | -260559.7                    |                              | -192280.7            |                              | -118484.3              |                              | -143910.1                         |

Model estimated via negative binomial regression for Minutes Online, Number of Logins, and Number of Days Visited. Model estimated via OLS for Logins per Day.

Standard errors in parentheses; \* p < 0.10, \*\* p < 0.05, \*\*\* p < 0.01; two-tailed test.

<sup>a</sup> Marginal effects represent the expected change in the dependent variable due to a one-unit increase in the independent variable (which is the change from 0 to 1 for an indicator variable).

<sup>b</sup> Marginal effects are the same as the coefficients, given the model's linearity.

<sup>c</sup> The constant represents the predicted value of the dependent variable for a non-Facebook connected male between ages 12 and 17 on the first day of the sample period (given the inclusion of the fixed effects for Day Registered).

<sup>d</sup> Because Logins per Day = Number of Logins / Number of Days Visited, we necessarily omitted observations where Number of Days Visited = 0.

## APPENDIX B: FOR CHAPTER 3, BACKGROUND & ADDITIONAL ANALYSIS, STAGES 1-4

The following tables provide additional information for stages 1-4.

**Table 10: Stage 1 - Project Factors Rated**

|    | <b>Project Factor</b>                        | <b>Source</b>          | <b>Definition</b>   |
|----|--|------------------------|---|
| 1  | # and Diversity of platforms/installations   | COSYSM<br>O            | Number and diversity of sites, installations, operating environments and diverse platforms  |
| 2  | # levels in the WBS                          | COSYSM<br>O            | Number of applicable levels of the Work Breakdown Structure   |
| 3  | Analysis & Design Capability                 | COCOMO                 | Analysts' analysis and design ability, efficiency and thoroughness, and ability to communicate and cooperate  |
| 4  | Application Experience                       | COCOMO                 | The project team's overall level of experience building the current type of product under development.  |
| 5  | Architecture Risk                            | COCOMO                 | Number and criticality of risk items and extent to which critical risk items have been identified with resolution plans   |
| 6  | Code Complexity                              | Military<br>Cost Tool1 | Code that has a very high number of input and output paths making it very difficult to test, may perform real time mathematical intense functions, maybe constrained by the operating environment, maybe written in a highly secure environment, or involves new or novel algorithms or applications. Complex code tends to be found in functions that emulate or interface with the physical world, i.e. radar signal processing, missile detection, data links protocol implementation, and electronic warfare. Human interface is infrequent with this type of code. Key to identifying complex code is the difficulty in verifying and validating the code in a laboratory environment. |
| 7  | Complexity and extent of testing required    | Additional<br>Sources2 | Complexity and extent of testing required by the project  |
| 8  | Complexity of integration                    | Additional<br>Sources3 | Difficulty of integrating, verifying and validating software performance  |
| 9  | Complexity of migrating from legacy platform | COSYSM<br>O            | Complexity of migrating from the legacy system  |
| 10 | Database Size                                | COCOMO                 | Effort needed to assemble and maintain the data required to complete a test of the program  |
| 11 | Development Method                           | Additional<br>Sources4 | Type of development approach (incremental, waterfall, spiral, agile, etc.)  |
| 12 | Development Process Maturity                 | COCOMO                 | Based upon the SEI's Capability Maturity Model (CMMI) ratings of organization-wide software development process maturity  |
| 13 | Development Schedule Constraints             | COCOMO                 | Extent of the schedule constraint imposed on the project; defined in terms of the percentage schedule stretch-out or  |

|    |   |                     |  |
|----|---|---------------------|--|
|    |   |                     | acceleration with respect to a nominal schedule for a project requiring a given amount of effort   |
| 14 | Development Specification Constraints             | COCOMO              | Need for conformance to pre-established requirements or specifications   |
| 15 | Execution Time Constraints                        | COCOMO              | Amount of available execution time expected to be used by the system   |
| 16 | Language and Tool Experience                      | COCOMO              | Level of experience of the team with the software tools and language for the project   |
| 17 | Level of Required Documentation                   | COCOMO              | Level of required documentation and its suitability to life cycle needs  |
| 18 | Main Storage Constraints                          | COCOMO              | Degree of main storage constraint imposed on a software system or subsystem  |
| 19 | Multi-site Development                            | COCOMO              | Nature of project development site locations (from fully collocated to international distribution), and communication support between those sites (from surface mail and phone access to full interactive multimedia).   |
| 20 | Personnel Continuity                              | COCOMO              | Level of annual turnover of the development project team   |
| 21 | Platform Experience                               | COCOMO              | Extent of the project team's experience with modern and powerful platforms, including more graphic user interface, database, networking, and distributed middleware capabilities   |
| 22 | Predicted Minimum Code Change Rate in Maintenance | Military Cost Tool1 | Predicted minimal annual level (percent) of change of the software code  |
| 23 | Product Complexity                                | COCOMO              | Complexity of software under development in five areas: control operations, computational operations, device-dependent operations, data management operations, and user interface management operations  |
| 24 | Product Type (e.g., Mission Critical)             | Additional Sources5 | Type of Application, e.g. Nonprocedural (spreadsheet, etc.), Batch Application, Interactive Application, Batch Data Base, Interactive Data Base, Scientific/Mathematical Application, Systems or Support Application, Communications/Telecommunications Application, Process Control Application, Embedded/Realtime Application, Graphics/Animation/Image Processing Application; Robotics/Mechanical Automation Application, Artificial Intelligence/Expert System, Hybrid/Multiple Types (indicate primary type, secondary type) |
| 25 | Programmer Team Capability                        | COCOMO              | Capability of the programmers as a team rather than as individuals, in terms of their ability, efficiency, thoroughness, and the ability to communicate and cooperate  |
| 26 | Programming Language                              | Military Cost Tool1 | Type(s) of programming language used for the project.  |
| 27 | Required Reusability                              | COCOMO              | Accounts for the additional effort needed to construct components intended for reuse on the current or future projects   |
| 28 | Required Software Reliability                     | COCOMO              | Extent to which the software must perform its intended function correctly over a period of time and the severity of consequences if it does not  |
| 29 | Requirements Understanding                        | COSYSM O            | Extent of project team's understanding of systems requirements.  |

|    |                                       |                                 |   |
|----|---------------------------------------|---------------------------------|---|
| 30 | Requirements Volatility               | Additional Sources <sup>6</sup> | Extent to which requirements are changing and at which frequency (e.g., daily, weekly, monthly)   |
| 31 | Similarity to Previous Products       | COCOMO                          | Extent of similarity to previously developed products   |
| 32 | Software Development Life-cycle Phase | COCOMO 7                        | Phase of the software development life cycle (e.g., SRR, PDR, CDR)  |
| 33 | Team Cohesion                         | COCOMO                          | Accounts for the sources of project turbulence and extra effort due to difficulties in synchronizing the project's stakeholders: users, customers, developers, maintainers, interfacers, others |
| 34 | Technology Maturity                   | COSYSMO                         | Maturity, readiness and obsolescence of the technology in the project   |
| 35 | Use of Software Tools                 | COCOMO                          | Extent to which advanced software development tools are used during development   |

<sup>1</sup>Highly influential in and drawn from Navy cost estimation tool.

<sup>2,3</sup>Recommended by military software cost estimation texts. See

[http://www.stsc.hill.af.mil/consulting/sw\\_estimation/softwareguidebook2010.pdf](http://www.stsc.hill.af.mil/consulting/sw_estimation/softwareguidebook2010.pdf)

<sup>4</sup>Years of evolving development methodologies based on the premise of performance improvements (CITE David and Guy 2003)

<sup>5</sup>See Endres and Albert's handbook on software systems engineering and Caper's work on software assessments (CITE).

<sup>6</sup>See Briand's work assessing software cost estimation modeling techniques (CITE).

<sup>7</sup>COCOMO parameter option

COCOMO product factor "Platform Volatility" omitted given established long-term stability of military aircraft platforms.

**Table 11: Stage 2 - Points Coded for Responses to AHP Survey**

| <b>Response</b>               | <b>Points</b> |
|-------------------------------|---------------|
| very much less important than | 1/7           |
| much less important than      | 1/5           |
| somewhat less important than  | 1/3           |
| equally important to          | 1             |
| somewhat more important than  | 3             |
| much more important than      | 5             |
| very much more important than | 7             |





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