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Disruptive and Sustaining Technology Development Approaches in Defense Acquisition

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Panel 18. Enhancing Small Business Participation in Defense Acquisition

Thursday, May 15, 2014	
1:45 p.m. – 3:15 p.m.	**Chair: Rear Admiral Seán F. Crean,** U.S. Navy, Director, Office of Small Business Programs, Department of the Navy ***Disruptive and Sustaining Technology Development Approaches in Defense Acquisition*** Gene Warner, OUSD(AT&L) Manufacturing and Industrial Base Policy ***Analyzing Patents Generated by SBIR Firms*** Toby Edison, Defense Acquisition University ***Increasing the Department of the Navy's Opportunities for Small Business and Non-Traditional Suppliers Through Simplified Acquisitions Contracting and NAICS Targeting*** Max Kidalov, Naval Postgraduate School Jennifer Lee, Naval Postgraduate School

Disruptive and Sustaining Technology Development Approaches in Defense Acquisition

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Abstract

This study explores the relationship between an organization's technology development approach (TDA) and its success in winning SBIR Phase 1 competitions. The research posits a difference in SBIR Phase 1 success between companies using sustaining and disruptive TDA. Companies responding to DARPA SBIR Phase 1 solicitations are surveyed to determine their approach to developing technology solutions. A newly developed instrument is used to identify disruptive and sustaining TDA. Demographic data, SBIR success, and data on TDA are collected. Principal axis factoring was used to identify four orthogonal factors related to TDA. The factors were interpreted and a new objective scale was developed to measure sustaining TDA. No equivalent scale was developed for disruptive TDA. Correlation and regression analyses indicated TDA is a contributing factor in SBIR Phase 1 success. Focus on the defense market and company inventiveness as measured by patent activity are also predictors. The findings indicate TDA mediates a company's focus and success at winning SBIR Phase 1 contracts. Implications for defense acquisition and disruptive innovation are discussed. A new conceptual framework linking focus, capability, inventiveness, and TDA with SBIR Phase 1 success is proposed for further research.

Introduction

Since the end of World War II, advanced technology has been the foundation of U.S. military strategic advantage. The Department of Defense (DoD) consistently invests $60 billion to $80 billion per year on weapons system research and development to maintain and increase the technology advantage (USD(C), 2013; Watts, 2008). These investments dwarf similar investments of other industrialized nations; Canada, for example, projects R&D, procurement, and operations investment over 20 years equivalent to a single year's U.S. defense budget (Jenkins, Castelli, Cianfarani, Fraser, & Nicholson, 2013).

The United States is arguably second-to-none in aggressively harvesting the best technologies for incorporation into weapons systems, but it comes at a very high price. Most of the investment since World War II has been used to refine and produce technologies that existed prior to that conflict (Guilmartin, 1994). The conceptual bases of nuclear weapons and radar were understood in the 1920s and late 1930s. Rocketry, jet propulsion, radar, and aircraft advances were driven by the focused application of improved production and design capabilities. The Cold War was the evolutionary pressure for developing the entire nuclear industrial base. The R&D focus since that time, enabled by the unique structure of the U.S. defense industrial base, has encouraged the continued emphasis on sustaining technologies while giving less emphasis to the systematic encouragement and support of disruptive technologies.

Disruptive Innovation

Disruptive technologies and scenarios have defining attributes (Christensen, 1997). Disruptive technologies are existing technologies configured in novel ways or placed in an entirely new architecture. They typically have lower performance in the primary performance dimension, but they often are cheaper to implement or operate. They usually have performance in secondary areas that make them attractive to an underserved, or new, market. Finally, their value network, or supporting supplier and talent infrastructure, is smaller and cheaper than the value network of the legacy technology.

The disruptive scenario is usually one of the disruptive technology making inroads into the legacy technology market share at the low end of a market. The cheaper value networks of the disruptive technology, coupled with attractive secondary performance characteristics, represents a good value proposition to the segment of the market that cannot afford the market-leading technology. Christensen (1997) built this scenario from the history of the computer disk drive market. As computers became smaller, so did the memory disk drives offered by new entrants to the drive market. These new entrants produced 8" disk drives for the emergent mini-computer market and, in the process, acquired market share from legacy disk drive vendors who had previously been successful in producing larger drives.

This scenario repeated itself with the advent of the personal computers. A new set of disk drive vendors successfully marketed the 5 ¼" and 3 ½" drives and eventually displaced the 8" drive vendors. In each case, the disruptive disk drive was developed from existing technology, initially had diminished performance compared to the legacy technology, and had attractive secondary attributes for a new or underserved market. While cost per megabyte of storage was higher than for legacy drives, the form factor was an attractive feature for the emerging personal computer market.

Disruptive innovation also operates on the scale of an entire market. The story of Eastman Kodak reconfigured the architecture of the entire photography market by introducing an existing, but unused, film technology into the camera itself and altering the nature of the photofinishing process (Lucas Jr. & Goh, 2009; Utterback, 1995). George Eastman replaced the emulsion-covered glass plates of the large format cameras with a flexible film that could be rolled up into a cheaply produced box camera—the "Brownie." His company then assumed the task of processing the exposed film, a business move that opened up the field of photography to average consumers. This change in the business architecture yielded a tremendously attractive performance advantage for the box camera. While a large format view camera would always take superior quality pictures, it was only available to those with expertise in, and desire to, chemically process the film. The Kodak box camera took lower quality photos, but was very accessible to the casual hobbyist. Over time, the quality of "casual photo" pictures improved, driving large format photography into a niche market.

A century later the scenario repeated itself in amateur photography. Kodak had become locked into their century-old business model to the point where they saw themselves as a chemical and film company instead of a company dealing in imaging (Lucas & Goh, 2009; Utterback, 1995). Despite owning the seminal patents for digital photography, Kodak was slow to develop a digital camera and accompanying business model for the digital imaging market. Computer and technology companies such as Sony, Canon, and Hewlett-Packard established an early and persistent presence in the market. After the mid-1990s, Kodak was unable to carve out a profitable niche and is currently in bankruptcy, while still making film for specialized markets.

Disruptive Innovation and Defense Acquisition

Literature in defense acquisition emphasizes the need for developing disruptive technologies, but often the term is misused when compared to its classical definition.

Reference to disruptive technology in a military context is often confused with any new technology. The disruptive scenario in the military acquisition literature casts disruption as neutralizing or frustrating an adversary's strategic or tactical advantage (Johnson & McLaughlin, 2007; Shannon, Yarbrough, & Johnson, 2010). Consequently the searches for what are called disruptive technologies and innovations usually address improving sustaining technologies in already existing architectures. This fundamental misunderstanding of disruptive innovation in the military context hampers the search for truly disruptive architectures.

The famed British Admiral Sir John Jellicoe was frustrated by the relative ineffectiveness of British surface combatants in World War I, even though in the *Dreadnought* class of battleships Britain and the Allies had very advanced technology in steam turbine propulsion and advanced fire control. Equivalent technology today would be termed disruptive, but in reality these advances were extensions of existing technologies. The technology was not only easily matched by adversaries, but was ineffective for either side, in part because the command and control architecture of naval surface combat had changed little since the Napoleonic wars (Brooks, 2007; Hoffman, 2004; Mukunda, 2010).

Naval warfare in World War I experienced disruption, but not because of any advanced technology. The true disruption was in the use of submarines against Allied shipping by Germany and the anti-submarine tactics response of the Allies. Germany changed the architecture of naval warfare by ceding the high seas to the British surface fleet and preying on transatlantic commercial shipping. This tactic was very effective for the first two years of the conflict, in part because the British Admiralty did not view protection of commercial shipping as part of its mission. In the parlance of disruptive innovation theory, this was not part of the "market" in which it wished to engage. By using the submarine, an existing technology, in a new role Germany reconfigured the architecture of naval warfare. After massive shipping losses, the Allies responded to the new architecture by adapting anti-submarine tactics and organizing transatlantic convoys for commercial shipping. It is interesting to note that the Allied response also used existing technologies, again in a different role.

After World War II the architecture of warfare emphasized production efficiency and operational maneuver (Guilmartin, 1994). The acquisition policies and market forces, since the 1950s, have favored and promoted sustaining technology development to fit this emphasis. The implicit assumption has been that the outcome of future conflicts would again be dependent on production and operational maneuver (Guilmartin, 1994; Watts, 2008; Watts & Harrison, 2011). The recent conflicts in Iraq and Afghanistan signal that this warfare architecture may be about to change.

This trend of searching for disruptive innovations, while actually focusing on and funding sustaining technologies is becoming increasingly expensive and arguably unsustainable (GAO, 2005, 2006, 2006a, 2006b). Supporting sustaining technologies is critical and necessary to maintaining the U.S. technological edge; however, identifying and nurturing disruptive innovation in the classic sense of the term could arguably yield solutions that are truly innovative and at a lower cost. It is not an either-or choice, but rather one of balance in efforts, resources, and focus. This study begins to address the focus by characterizing the technology development approach (TDA) of a company as either intrinsically sustaining or disruptive, and assessing whether their technology solutions are the preferred ones in an acquisition competition.

Significance of the Study

This study examined the technology development approach (TDA) of small innovative companies and established a quantitative relationship between TDA and success in defense acquisition contracting. Establishing such a relationship is a key indicator of whether a company's TDA addresses a disruptive or sustaining focus in technology development in a deliberate and systematic way. Establishing metrics for sustaining and disruptive TDA would give defense R&D professionals a significant tool to assess whether a company has the potential for producing disruptive technology solutions.

The results also fill a gap in the development of disruptive innovation theory, that is, the lack of predictive effectiveness in the theory itself (Danneels, 2004, 2006; Markides, 2006; Tellis, 2006). A known weakness in disruptive innovation theory lies in the terminology. The term "disruptive" is used to describe an attribute of the technology as well as a technology solutions effect on its market. As with defense acquisition, establishing objective metrics for sustaining and disruptive TDA begins to separate the technology attributes from the market effects.

Study Overview

This was a non-experimental, exploratory study designed to identify disruptive and sustaining TDA in small innovative companies. Companies participating in the U.S. government Small Business Innovative Research/Small Business Technology Transfer (SBIR/STTR) program were sampled with a new instrument designed to measure disruptive and sustaining TDA (DoD, 2013). The instrument collected primary data on company demographics such as total revenues, company age, number of employees, and so forth. It also measured company TDA preference through 12 Likert-style statements developed from disruptive innovation theory and systems engineering practices.

The study design posited that TDA would be a primary driver for success in competing for SBIR/STTR contracts. The initial concept framework is at Figure 1.

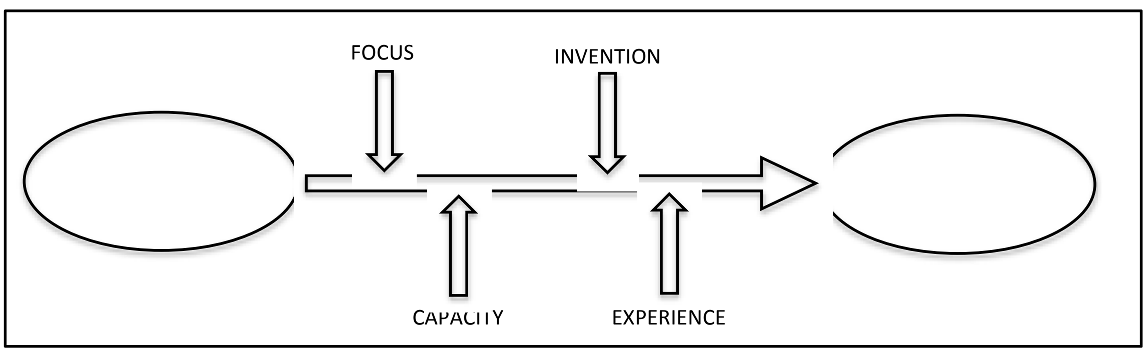

Figure 1. Initial Study Concept Diagram

The TDA, either disruptive or sustaining in nature, would be mediated by a company's focus, capacity, invention or inventiveness, and experience. Company focus was measured by a company's revenue from defense contracts. Inventiveness was measured by the patent activity of a company. Capacity related to the scientific and technical staff employed by a company, and the age of a company was the measure for experience.

The primary variable TDA is a new construct derived from responses to the Likert-style statements of the survey instrument. The survey responses were subjected to a dimension reduction and potential measurement scales for sustaining and disruptive TDA were developed. With a quantified measure of TDA, the demographic data were subjected to a multivariate regression and correlation analysis to determine the relative contributions of the independent variables.

Research Questions and Hypotheses

This study poses two research questions and associated hypotheses:

> RQ_1: What is the relationship among the independent variables of TDA, company demographics, and the criterion variable of winning Phase 1 SBIR defense contracts?
>
> RQ_2: What are the relative contributions of TDA and company demographics to winning SBIR Phase 1 contracts?

The first research question is designed to identify any relationship among the way companies develop their technology solutions, the demographic profile of the company, and the criterion variable of winning SBIR Phase 1 contracts. The second research question attempts to quantify the identified relationships of RQ_1.

The aim of the study is to examine four hypotheses in support of answering the research questions:

> $H_0$1 There is no significant difference between technology development approaches in winning SBIR Phase 1 defense contracts.
>
> $H_1$1 There is a significant difference between technology development approaches in winning SBIR Phase 1 defense contracts.
>
> $H_0$2 There is no significant relationship between TDA and the contribution of the demographics INVENTION, CAPACITY, FOCUS, and EXPERIENCE of companies who win SBIR Phase 1 defense contracts.
>
> $H_1$2 There is a significant relationship between TDA and the contributions of the demographics INVENTION, CAPACITY, FOCUS, and EXPERIENCE of companies who win SBIR Phase 1 defense contracts.

Hypotheses $H_0$1 and $H_1$1 are designed to determine whether disruptive or sustaining TDA are related to success in SBIR Phase 1 competitions. The Hypotheses $H_0$2 and $H_1$2 test for the significance of the relationship of TDA with the demographic variables of the company.

Population/Sample

The target population was small innovative companies engaged in developing technology solutions. Companies participating in the SBIR/STTR program were used as a surrogate for this population. The regulations for company participation stipulated American companies with a staffing of less than 500 (DoD, 2013). The research focused on companies competing for SBIR Phase 1 contracts. Technologies at the Phase 1 level aligned well with a key attribute of disruptive technologies, that is, technologies that have yet to develop a significant value network providing institutional or market support (Christensen, 1997; Christensen & Raynor, 2003).

The sampling frame was developed from companies responding to Defense Advanced Research Project Agency (DARPA) SBIR Phase 1 solicitations between 2007 and 2013. This yielded a sampling frame of 462 companies. Companies were randomly selected from the sampling frame to participate in the study. Organizations signaling interest were sent an information package detailing the study and a copy of the survey instrument. Companies wishing to participate were sent an email invitation given them access to the survey instrument hosted on the SurveyMonkey.com commercial website.

Survey Instrument Validation and Data Collection

The survey instrument was specially developed for this study. Consequently no validity or reliability data were available. Field and pilot tests were conducted to confirm the survey's usability and its reliability. Practitioners in program management and industrial base analysts reviewed the survey instrument in a field test and suggested changes in wording to improve readability.

The pilot test involved responses from nine companies selected at random from the sampling frame. Of particular interest were the 12 Likert-style survey items measuring TDA. These measurements would form the basis for scales measuring disruptive and sustaining TDA. Table 1 lists pilot test results with respect to scale reliability of the 12 statements measuring TDA.

Table 1. Item Deletion Effects on Cronbach's Alpha

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
TDA15	38.71	51.238	.507	.858
TDA16	38.00	44.667	.784	.837
TDA17	38.14	44.476	.717	.842
TDA18	37.86	51.810	.226	.882
TDA19	38.00	44.667	.596	.854
TDA20	37.57	48.286	.634	.849
TDA21	37.86	40.476	.956	.820
TDA22	37.57	51.619	.815	.851
TDA23	38.00	54.000	.270	.869
TDA24	37.00	55.333	.148	.875
TDA25	38.14	53.810	.325	.866
TDA26	37.29	47.238	.861	.838

The 12 items, TDA15–TDA26, displayed high values of Cronbach alpha when taken as a composite scale. Deleting any one item from the scale had minimal effect on the scale validity and only depressed the scale to 0.820. This is well above the Cronbach alpha standard of 0.7 for valid and reliable scales. No changes were made to the survey instrument after the pilot test and the research moved on to the full-scale study.

A total of 70 companies were randomly selected and contacted from the original sampling frame of 420 organizations. Of these 70 companies, 36 expressed interest and requested further information. Study details and a copy of the survey were sent with a secure email link to the survey instrument. A total of 18 companies completed the survey, yielding 16 usable responses. The final response rate for the full-scale study was 22.8%.

Factor Analysis and Scale Development

Data analysis was performed in a specific sequence. Descriptive statistics were calculated on the demographic and TDA responses. Factors from the TDA data were extracted, retained, and interpreted. Potential scales for disruptive and sustaining TDA were developed. Finally, new independent variables for TDA were developed from the scales and, along with the collected demographic data, were regressed against a company's success in winning SBIR Phase 1 awards.

Factor Extraction

The 12 survey items addressing TDA were designed to measure the level of sustaining or disruptive TDA of each of the participating companies. The Likert-style responses were dimensionally reduced via principal axis factoring and yielded 12 factors.

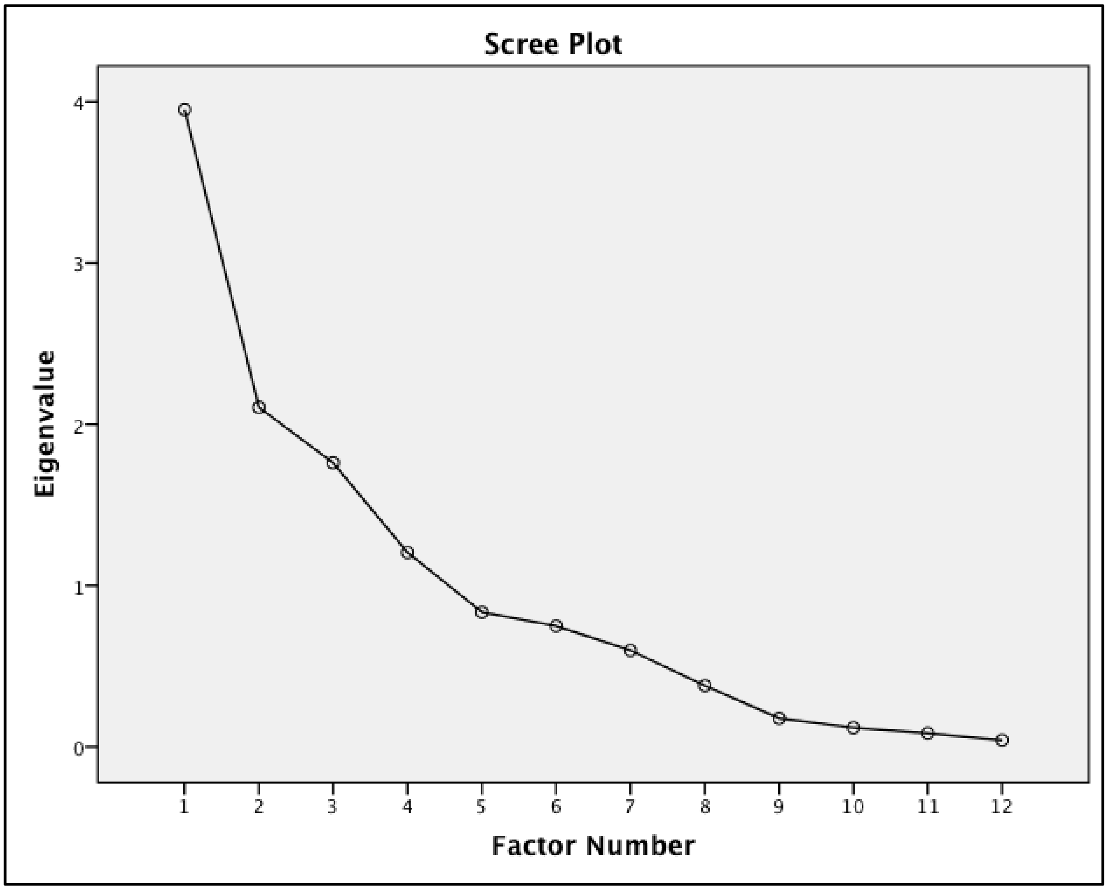

Figure 2. Scree Plot of Extracted Factors

The first four factors accounted for ~75% of the variance in the TDA data. Factors 5–12 displayed relatively little contribution and were judged to be not significant in developing metrics for TDA. The four strongest factors were subsequently retained for further analysis.

The four factor solutions were rotated with a Direct Oblimin transformation to obtain optimized loading of the contributing survey items on the identified factors. The structure matrix identifies the correlation of the survey items with the four retained factors.

Table 2. Structure Matrix for TDA

	Factor			
	1	2	3	4
TDA16	.813	.118	-.074	.537
TDA21	.774	-.139	-.236	.500
TDA17	.716	-.243	.206	.037
TDA15	.617	-.264	-.325	-.238
TDA19	.508	-.411	-.463	.248
TDA26	.725	-.783	-.223	-.093
TDA23	.363	-.708	-.150	.045
TDA22	-.017	-.607	-.211	-.149
TDA20	.024	-.529	.388	-.027
TDA24	.150	.091	.710	.157
TDA18	-.341	.176	.649	.096
TDA25	.062	.063	.134	.793

Extraction Method: Principal Axis Factoring

Rotation Method: Oblimin with Kaiser Normalization

Factor Loading

The survey items highlighted in Table 2 are the highest loading survey items on the four retained factors. Best practice with factor analysis is to consider loading item loadings above an absolute value of 0.3 to be significant for factor interpretation(R. S. Cooper, 2003; Costello & Osborne, 2005; Gorsuch, 1997). At least four survey items load at this or higher level on each of the retained factors. Each factor has enough items to form workable scales for establishing TDA, subject to interpretation of the factor matrix.

Factor Interpretation and Scale Reliability

The highest loading survey items for Factor 1 are characteristic of sustaining TDA. Factor 2 loading was associated with survey items describing technology architectures or market effects. Factor 3 displays survey items with attributes of both sustaining and disruptive TDA as well as significant cross-loading with Factors 1 and 2. The items loading strongly on Factor 4 were mostly redundant with Factor 1.

Sustaining TDA was well described by Factor 1 while Factor 2 showed promise as a construct for disruptive TDA. The other two factors were ambiguous; however, scales were constructed and analyzed to determine the validity and suitability for including any of the factors in the following regression analysis. Table 3 lists the Cronbach alpha for each of the four factor scales constructed from the contributing survey items. Table 4 is an analysis of the robustness of each scale.

Table 3. Cronbach Alpha for Prospective Factor Scales

Factor	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items
1	.833	.833
2	.727	.730
3	.448	.522
4	.762	.752

N = 4 scale items for each factor

Table 4. Scale Robustness

Factor	Cronbach's Alpha	Cronbach Alpha Range	Item Deletion Sensitivity
1	.833	.757 – .832	0
2	.727	.601 – .753	3
3	.448	.227 – .526	n/a
4	.762	.532 – .803	2

Three of the four factors support scales with acceptable alpha values of 0.7, suggesting good reliability with scale constituents that are complementary without being redundant (Gliem & Gliem, 2003; Gorsuch, 1997; Tavakol & Dennick, 2011). The scale for Factor 3 falls well below this level, making the factor unsuitable for inclusion in further analysis.

The robustness of the scales is measured by the effect of item deletion. The scale for Factor 1 maintains acceptable alpha values regardless of item deletion. Scales for Factors 2 and 4 indicate fragile reliability; alpha values fall when at least two items of either scale are deleted.

Factor Retention

Factor 1 is retained for further analysis, based on the homogeneity of the component survey items and the robustness of the resultant scale. The scale from Factor 1 is measures the construct *sTDA*, an independent variable used as a measure of sustaining TDA. Factor 2 is rejected because of its heterogeneous mix of survey items and fragility of the resultant scale (D. R. Cooper & Schindler, 2011; Gorsuch, 1997; Vogt, 2007). Factors 3 and 4 are rejected due to inadequate scales in the case of the former and redundancy with Factor 1 in the case of the latter.

Research Questions and Associated Hypotheses

The research questions were addressed with a mix of correlation and regression analyses. The questions RQ_1 and the associated hypotheses H_01 and H_11 explore the quantitative relationships among sTDA, the collected demographic data, and success at winning SBIR Phase 1 contracts. The question RQ_2 and associated hypotheses H_02 and H_12 determine the contributions of the same independent variables and demographics in winning SBIR Phase 1 contracts.

Research Question 1 and Hypotheses H_01/H_11

Research Question 1 addresses the relationships among TDA, company demographics, and SBIR Phase 1 success:

> **RQ_1** What is the relationship among the independent variables of TDA, company demographics, and the criterion variable of winning Phase 1 SBIR defense contracts?

Correlation among sTDA and the demographic variables successfully addresses this question. Table 5 contains a description of the demographic variables and the construct sTDA and Table 6 is the resulting correlation matrix.

Table 5. Demographic Variable Definition

Variable Name	Definition	Data Type
EXP01	Company age (years)	ratio
CAP02	Total employment	ratio
CAP03	Total Science & Technical Staff	ratio
EXP04	SBIR Phase 1 Applications	ratio
EXP05	SBIR Phase1 Awards	ratio
INV06	Patent applications	ratio
INV07	Patents granted	ratio
FOC08	Total annual revenue	ratio
FOC09	SBIR Phase 1 & 2 revenue	ratio
FOC10	Total defense revenue	ratio
sTDA	Sustaining Technology Development Approach	ratio

Table 6. Correlation Matrix for Predictor and Criterion Variables

	EXP01	CAP02	CAP03	EXP04	EXP05	INV06	INV07	FOC08	FOC09	FOC10	sTDA
EXP01	1										
CAP02	.174	1									
CAP03	.420	.179	1								
EXP04	.474*	.074	.791**	1							
EXP05	.626**	.253	.776**	.802**	1						
INV06	.351	-.027	.568*	.753**	.601**	1					
INV07	.315	-.004	.621**	.601**	.441*	.807**	1				
FOC08	.291	.407	.623**	.701**	.581**	.588**	.520*	1			
FOC09	.405	.374	.678**	.351	.737**	.237	.218	.285	1		
FOC10	.266	.435*	.479*	.693**	.547*	.579**	.496*	.896**	.271	1	
sTDA	-.137	.336	.297	.316	.353	.067	.120	.431*	.219	.367	1

* Correlation is significant at the 0.05 level (1-tailed).

** Correlation is significant at the 0.01 level (1-tailed).

The criterion variable EXP05 is strongly and significantly correlated with all the demographic variables except for CAP02, and displays a weak correlation with sTDA, the construct for sustaining technology development.

The Hypotheses $H_0 1$ and $H_1 1$ were designed to measure the difference in sustaining and disruptive technology development approaches in SBIR Phase 1 competitions.

> **$H_0$1** There is no significant difference between technology development approaches in winning SBIR Phase 1 defense contracts.
>
> **$H_1$1** There is a significant difference between technology development approaches in winning SBIR Phase 1 defense contracts.

While a metric for sustaining TDA was established through factor analysis and scale development, no analogous measure could be developed for disruptive TDA. A factor was extracted with attributes of disruptive TDA; however, its scale reliability was inadequate to properly develop a reliable construct. Consequently, the research could only measure sustaining TDA.

Research Question 2 and Hypotheses $H_0 2$/$H_1 2$

Research question RQ_2 attempts to quantify the contribution of company demographics and TDA to SBIR Phase 1 success. The hypotheses $H_0 2$ and $H_1 2$ are designed to determine whether those contributions are significant.

> **RQ_2** What are the relative contributions of TDA, and company demographics to winning SBIR Phase 1 contracts?
>
> **$H_0$2** There is no significant relationship between TDA and the contribution of the demographics INVENTION, CAPACITY, FOCUS, and EXPERIENCE of companies who win SBIR Phase 1 defense contracts.
>
> **$H_1$2** There is a significant relationship between TDA and the contributions of the demographics INVENTION, CAPACITY, FOCUS, and EXPERIENCE of companies who win SBIR Phase 1 defense contracts

This study regressed the number of SBIR Phase 1 successes against the demographic data and sTDA to determine regression coefficients in a standard linear regression model:

$$EXP05 = a + B_1(sTDA) + B_2(EXP01) + B_3(CAP03) + B_4(INV06) + B_5(FOC09) + e \quad (1)$$

The variables used in the regression analysis are listed in Table 7.

Table 7. Regression Analysis Variable Definition

Variable	Type	Definition
EXP05	Dependent	SBIR Phase 1 awards
sTDA	Independent	Sustaining TDA
EXP01	Independent	Company age
CAP03	Independent	Science and technical staff
INV06	Independent	Patent applications
FOC09	Independent	Revenue from SBIR Phase 1 and 2 award

The variables chosen for analysis are a subset of the survey data and represent the constructs of focus, inventiveness, experience, capacity, TDA, and SBIR success described in the concept diagram of Figure 1. Tables 8 and 9 summarize the results of the regression analysis.

Table 8. Regression Analysis Summary

R	R^2	Adjusted R^2	SE of the Estimate	Change Statistics				
				R^2 Change	F Change	df1	df2	Sig. F Change
.932[a]	.869	.803	17.654	.869	13.240	5	10	.000

Predictors: (Constant), FOC09, STDA, INV06, EXP01, CAP03

Dependent Variable: EXP05

Table 9. Regression Analysis Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-53.001	20.952		-2.530	.030
STDA	2.742	1.334	.260	2.056	.067
EXP01	1.362	.535	.349	2.545	.029
CAP03	.645	1.085	.117	.594	.566
INV06	1.821	.886	.302	2.056	.067
FOC09	6.888E-006	.000	.388	2.344	.041

Dependent Variable: EXP05

The regression model explains ~87% of the variance in the criterion variable of success in winning SBIR Phase 1 contracts. Company age and experience, EXP01 and FOC09, respectively are the strongest predictors of SBIR Phase 1 success, followed by the variables for inventiveness and TDA, INV06 and STDA, respectively. The strongest predictors are significant at $p < 0.05$ level. The coefficients for STDA and INV06 are slightly less significant, each with a value of $p = 0.067$. The construct for capacity, that is, the number of science and technical staff represented by CAP03 appears to have the weakest predictive value in the regression model.

Conclusions

Both research questions and one set of hypotheses were successfully addressed in this study. The data successfully addressed RQ_1 and established a quantifiable relationship among the demographic variables, TDA, and success in competing for SBIR Phase 1 contracts. The collected data could not address the Hypotheses $H_0 1$ and $H_1 1$ designed to discern a significant difference in effectiveness in disruptive or sustaining TDA. This was due to the fact that disruptive TDA could not be reliably measured. A reliable measurement for sustaining TDA, sTDA, was established and used in the analyses for RQ_2 and Hypotheses $H_0 2$ and $H_1 2$.

The demographic variables representing company experience, focus, inventiveness, capacity, and TDA were found to be significant contributors to the success of a company in competing for SBIR Phase 1 contracts. The linear regression model indicates that company age and focus on defense projects proved to be the strongest predictors of SBIR Phase 1 success. Inventiveness and a sustaining TDA were also significant predictors, although at a lower level than experience and focus. Capacity, as measured by the number of science and technical staff, was found to have minimal, significant contribution to SBIR Phase 1 success. The results support the initial conceptual framework of Figure 1; however, in the following section the discussions and implications for theory indicate ways to improve the framework.

Discussion, Theory Implications, and Recommendations

The concept framework for this study was developed from the literature describing disruptive innovation and architectural configurations. The extant literature strongly indicated that differing technology approaches were deliberate choices that manifested themselves in the architecture of technology solutions (Brusoni & Prencipe, 2011; R. Henderson, 1993; R. M. Henderson & Clark, 1990). This was partially borne out by the study results. The survey instrument was able to reliably identify a sustaining TDA among the companies sampled.

Analyses of the data also successfully quantified the relative contributions of TDA, inventiveness, experience, capacity, and focus on winning SBIR Phase 1 contributions. The results allow fruitful discussion on the disruptive innovation theory, defense acquisition, and technology development strategies in small companies, the concept framework used in this study, and the characterization of technology development itself.

Characterizing TDA

A failure of this study opened up an unexpected avenue of discussion regarding the nature of technology development. The instrument used in this study reliably measured sustaining TDA but failed to identify a reliable scale for disruptive TDA. The principal axis factoring analysis identified a potential factor that could be characterized as the basis for disruptive TDA; however, the component elements were too dissimilar to make for a reliable construct.

The fact that the instrument could discern sustaining TDA and not find a disruptive analog raises the question of whether disruptive TDA can be developed as a homogeneous construct. The identified variable sTDA displayed homogenous and strongly related components, as anticipated from the extant literature (Christensen, 1997; Christensen & Raynor, 2003; R. Henderson, 1993; R. M. Henderson & Clark, 1990). The incoming study assumption was that disruptive TDA would show a similar level of homogeneity. The failure to do so highlights what the literature usually identifies as a weakness in disruptive innovation theory. Instead of a weakness, the results may confirm the heterogeneous nature of disruptive TDA as an accurate description of the construct.

Disruptive innovation theory has been validly criticized as being weak in its predictive effectiveness (Danneels, 2004, 2006; Markides, 2006; Sood & Tellis, 2011; Tellis, 2006). A measure of this weakness lies in the way the theory was originally articulated. The same terminology describes not only an intrinsic attribute of the technology, but also as a way to describe market effects. Most of the extant literature focuses on market effects with only a few concentrating on finding ex ante indicators of disruptive technology (Christensen, 1997; Govindarajan & Kopalle, 2006).

The results of this study support the notion that disruptive TDA may be an alternate TDA that is compositionally more diverse than its sustaining TDA analogy. This study assumed TDA was a fixed attribute of a company’s technology development strategy. With a choice of TDA—sustaining or disruptive—a company could use approaches that best fit technology development requirements. Company development approaches vary from the linear and deliberate to less structured and more free-wheeling (Chaffee, 1985; Miles, Snow, Meyer, & Coleman, 1978; Snow & Hrebiniak, 1980). Incorporating lessons learned from the market in developing technology solutions is a viable strategy in a competitive market (Lampel & Shamsie, 2003; Mintzberg, 1979; Mintzberg & McHugh, 1985; Pascale, 1984). Coupled with the relatively weak contribution of TDA to SBIR Phase 1 success it could be that TDA is a mediating, rather than primary, driver of SBIR Phase 1 success, and a tool that is a mixture of disruptive and sustaining approaches to technology development.

TDA and Defense Acquisition

The study results would indicate that sustaining TDA is the preferred approach of small innovative companies developing technology solutions. Such a conclusion would be consistent with the general direction of defense technology development used by the industrial base since the end of World War II (Guilmartin Jr., 1994; Watts, 2008; Watts & Harrison, 2011). Sustaining technologies in defense acquisition have large, well-established value networks in a market with large barriers to entry (Christensen, 1997; Porter, 1980; Porter, 2008). It is also a market that tends to be risk-averse with respect to launching new technology architectures that are the essence of disruptive innovation, favoring incremental, albeit expensive, expansion of existing architectures primarily because of their existing value networks (GAO, 2006, 2006b, 2007; Meier, 2008).

The notion of TDA being a scenario-specific tool may account for the preponderance of sustaining TDA in this research. Defense organizations invest their research and development funds carefully, even at the SBIR Phase 1 level. Companies competing for such funds will be sensitive to how their nascent technology may fit in with the existing value network of a prospective customer (Audretsch, 2003; Wallsten, 2000). A complementary study to this one would be to control for the wording and scope of the SBIR Phase 1 solicitations when assessing TDA.

The preference for sustaining technologies may be at work on the customer side of the SBIR Phase 1 process. Representative from defense agencies are used to assess Phase 1 proposals for feasibility. This assessment may introduce an element of selection bias if assessment agents are conceptually or technically invested in the value networks of previously acquired products. Truly disruptive solutions would likely be discounted if they represent to big a departure from the state-of-the-practice of the legacy technology. The idea of a selection bias is entirely consistent with disruptive innovation theory. Legacy solutions with known characteristics and measurable value networks are attractive alternatives to the unknowns of new architectural configurations (Christensen, 1997; Christensen & Raynor, 2003; Guilmartin, 1994).

Recognizing this selection bias in defense acquisition means that any disruptive TDA would be a relatively small presence related to sustaining TDA. To offset this bias the study sampling frame was drawn from DARPA solicitations on the assumption that the requirements for the technology solutions would be less defined and conducive to alternate technology architectures. Follow-on studies controlling for sampling frame composition may be more effective at isolating disruptive TDA. It is encouraging that a factor representing disruptive TDA could be isolated, even if it proved unsuitable for further analysis in this study.

Revisiting the Conceptual Framework

This exploratory study posited a conceptual framework in Figure 1 where TDA was the primary driver for SBIR Phase 1 success. The resulting data collection and analysis gives an opportunity to review the framework and develop an alternate configuration for follow-on analysis. From the regression analysis it appears that a company's focus on SBIR projects with experience, measured in terms of company age, a mediating variable. Inventiveness and sTDA were found to be weaker contributors, with capacity contributing very little.

Two concepts from the discussion of this research suggest a rearrangement of the original framework. The first concept is where TDA is actually a supporting tool that is flexible in responding to the specifics of a given solicitation. This moves TDA away from being a primary factor to being a mediating variable. The second concept is to recognize the existence of some assessment bias on the part of organizations in selecting SBIR Phase 1 proposals. The reworked conceptual framework is found at Figure 3.

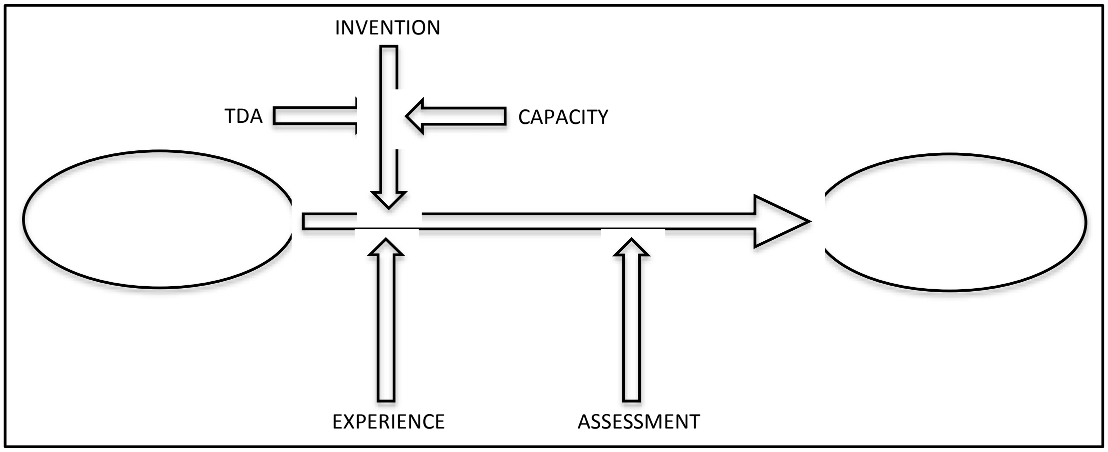

Figure 3. Modified Conceptual Framework

Focus is now the conceptual anchor for the construct with inventiveness, assessment, and experience being the main mediators. The main difference between this construct and the initial framework is the roles of TDA and capacity. They are now shown to be mediating inventiveness. Capacity was only a weak contribution to the criterion variable and in the new framework it is posited to have a more direct relationship to inventiveness. In a similar fashion, TDA characterized as a flexible tool would have a more direct effect on inventiveness. Science and technical staff would have the opportunity to blend disruptive and sustaining approaches to find the best mix in developing technology solutions. Assessment is a new, outside factor added to control for the posited assessment bias discussed earlier.

Recommendations for Future Work

The following recommendations are drawn from the above discussion and noted limitations of the study. They are structured to yield a more effective instrument for establishing sustaining and disruptive TDA and to increase the applicability to scenarios outside the defense context.

Enhanced sampling. The results of this study are limited in applicability, in part because of the relatively small sample of 16 respondents. A much larger sample size of 100–200 responses is recommended, which would add more confidence and precision in the dimension reduction step (Costello & Osborne, 2005). Increasing the sample size is perhaps the single most effective measure to clarify the ambiguities surrounding the constructs of sustaining and disruptive TDA.

A follow-on study would benefit from controlling for technology domains. While not examined in this study it is reasonable to assume that technology development of physical items may use different TDA than software. The sampled companies varied widely in terms of their technology domains. The new conceptual framework of Figure 3 posits TDA as a tool mediating inventiveness. A refinement of this research would be to determine if TDA for different technology domains could be quantified.

Survey instrument enhancement. The survey instrument used for this study would need to be revisited for a study based on Figure 3. The lessons of this study, particularly in regard to defining disruptive TDA, would need to be incorporated to define a more reliable construct and scale for disruptive TDA. A new section to measure assessment bias would be needed to properly integrate the new assessment construct of the concept framework.

Exploratory/confirmatory analysis. A new exploratory study should be conducted with the new conceptual framework, followed by a confirmatory study. Both should be done with a relatively large sample. A confirmatory study should be preceded by the development of a quantitative framework through the use of structural equation modeling.

Expansion to commercial domain. Successful confirmatory analysis would enhance the confidence in the concept framework to the point where generalizations could be made about TDA in larger companies with a commercial, non-defense focus. In this final study the sampling frame is unrestricted.

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