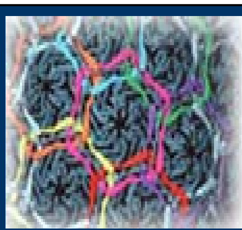

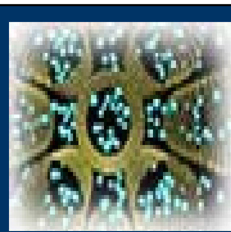

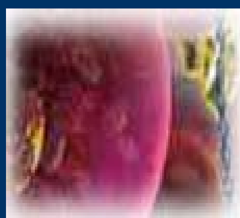

ENGINEERING INNOVATION

STRATEGIC PLANNING IN NATIONAL SCIENCE FOUNDATION-FUNDED ENGINEERING RESEARCH CENTERS

Report to the National Science Foundation

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NSF Award Number: EEC-0345195
Date Awarded: 9 April 2004
Disclaimer: Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF

ENGINEERING INNOVATION: STRATEGIC PLANNING IN NATIONAL SCIENCE FOUNDATION-FUNDED ENGINEERING RESEARCH CENTERS

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Acknowledgements

This material is based upon work supported by the National Science Foundation (NSF) under Grant No. EEC-0345195. We express our gratitude to Lynn Preston, Leader of the NSF's Engineering Research Centers Program and Deputy Division Director, and Linda Parker, Engineering Program Evaluation Director, for their generosity and guidance throughout this research. Lynn and Linda provided valuable insight on the Engineering Research Center (ERC) Program as a whole, and supplied timely information throughout our data collection effort. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

We also thank the members of our ERC technical advisory board:

David McLaughlin, Director, Center for Collaborative Adaptive Sensing of the Atmosphere at the University of Massachusetts.

Brij Moudgil, Director, Particle Engineering Research Center, University of Florida.

Robert Nerem, Director, Georgia Tech/Emory Center for the Engineering of Living Tissue.

Buddy Ratner, Director, University of Washington Engineered Biomaterials.

Farhang Shadman, Director, Engineering Research Center for Environmentally Benign Semiconductor Manufacturing, University of Arizona.

Michael Silevitch, Director, Center for Subsurface Sensing and Imaging Systems, Northeastern University.

These individuals not only provided valuable insight into their own ERC operations, but also about the ERC Program in general. They encouraged participation from their ERCs in our survey, which was invaluable in helping us attain a high response rate and, therefore, a representative sample of responses. Finally, many of these individuals invited us to conduct in-depth interviews with a broad range of personnel from their ERCs. Without such opportunities, we could not have attained an in-depth understanding of the inner workings and context of the ERCs.

The grant proposal to NSF was written in 2003 while Steve Currall was on sabbatical at the Graduate School of Business (GSB) at the University of Chicago. He wishes to thank Professor Steven N. Kaplan, Neubauer Family Professor of Entrepreneurship and Finance, and Professor John Huizinga, Associate Dean and Walter David "Bud" Fackler Distinguished Service Professor of Economics, for their generous support. The GSB at the University of Chicago provided a wonderful working environment.

We thank Professor Vicki Colvin of Rice University for facilitating initial contact with Lynn Preston regarding a study of strategic planning in ERCs. We also thank members of our extended research team for their assistance throughout this project. Specifically, Mary Somers Pyne and Timmie Wang at Rice University were extremely helpful in providing administrative support. We also thank Sally Chee and Cimon Chee for their dedication in entering and cleaning the datasets generated by this project.

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Executive Summary

This report, entitled "Engineering Innovation: Strategic Planning in National Science Foundation-Funded Engineering Research Centers," summarizes findings from a large-scale examination of the operational functioning of 22 Engineering Research Centers (ERCs) in the United States. Specifically, we studied the use of the National Science Foundation's (NSF) ERC Program's three-plane framework for developing each center's strategic plan. Further, we investigated the effect of strategic planning on two important ERC outcomes: research publication productivity and technology commercialization (i.e., research application) productivity.

The aim of the ERC Program, which is the flagship scheme for federally funded support of engineering in American universities, is to foster national well-being and economic competitiveness by promoting university-industry collaboration to maintain and advance the nation's technological leadership. Since 1985, the Program has been the producer of many leading edge technologies that would not otherwise be possible in traditional academic research settings. The ERC Program has also made a significant academic contribution through knowledge generation and dissemination in the form of publications and highly trained students.

Although the purpose of our study was not to evaluate the ERC Program, we could not help but be deeply impressed with its overall quality and the enormous positive impact it has on both academic research and America's leadership in science and engineering. The ERC Program is exemplary in its ability to foster collaborations between academe and industry. Other governmental funding schemes, both in the United States and around the world, should look to the ERC Program for inspiration and guidance.

"Engineering Innovation" in the title of this report, has a double meaning in that "Engineering" is used as both a verb and an adjective. "Engineering" is used as a verb in the sense that the *raison d'être* of the ERC Program is to create and foster new technical innovations (i.e., incremental or disruptive improvements to a technology, service, or standard). That is, ERCs are devoted to "engineering" (i.e., creating) new technical innovations. The word "Engineering" also is used as an adjective to describe the particular *type* of innovation that ERCs are designed to produce, namely, innovations in the field of engineering. Such innovations involve transforming basic science and engineering discoveries into systems and/or devices that address a societal problem or need. This form of engineering innovation that occurs within ERCs can be contrasted with other types of innovation, such as purely scientific innovations, which may create new knowledge but do not directly address a societal problem or need.

We personally visited 11 ERCs and conducted telephone interviews with at least one individual from each of the remaining 11 ERCs between January and September 2005. Further, we surveyed a range of ERC personnel received responses from 839 people in December 2005. Through our in-depth analysis of interview and survey data, as well as five years of ERC annual reports (2001-2005), we uncovered a number of important relationships among strategic planning, organizational outcomes, and individual attitudes.

Based on our empirical analyses, we concluded that the three-plane framework and a formal process of strategic planning were vital tools for organizing the research endeavor within ERCs. Also, the three-plane framework was a useful tool for illustrating each center's strategic plan. Yet, the method of implementing the three-plane framework critically determined whether it was beneficial to overall planning formality and quality of planning (i.e., comprehensiveness) and organizational outcomes. The most important determinant of whether planning benefited

organizational outcomes was the overall comprehensiveness of the planning, rather than commitment to the planning tool or process.

By surveying all ERC personnel, we uncovered several attitudinal factors that either inhibited or benefited strategic planning and, subsequently, organizational outcomes. Among the most important attitudes were psychological commitment to the ERC, acceptance of planning as a useful exercise, and knowledge of planning. We found that the planning process was beneficial only for organizational goals that were explicitly discussed and prioritized in planning. For example, technology commercialization productivity in ERCs was affected by strategic planning but research publication productivity was not.

Through our interviews we also uncovered a number of important themes concerning how ERCs make strategic plans. With regard to strategic planning, we discovered the importance of properly set expectations for the role of planning and reasonable implementation of planning requirements. We discovered several factors relating to acceptance of, or resistance to planning, including characteristics of individual centers and their leadership. Within ERCs, overall attitudes toward planning and the three-plane framework also depended strongly on the manner in which the framework was presented and described. A one-size-fits-all approach to the planning process was not appropriate; instead we advocate customizing the planning process in a manner that maximizes the quality of the strategic plan for each ERC. The leadership of the ERC Program understands that a one-size-fits-all approach is inappropriate so the ERC Program does not make strict requirements regarding the formality of the planning process. However, when requirements are set for particular components that all ERCs must include, the components should be carefully evaluated to ensure they benefit the quality of strategic planning for all types of ERCs.

ERCs are very diverse in their operations and their adoption of the strategic planning process as an organizational tool. ERCs must leverage their unique strengths in combination with generic principles concerning how best to formulate an organization's strategy. We hope our findings shed light and open future lines of communication on the best methods for organizing and managing ERCs.

History of the ERC Program

In 1985, the National Science Foundation (NSF) launched the Engineering Research Center (ERC) Program. The Program is the Nation's flagship vehicle for federally funded support of large-scale academic engineering research collaborations with industry. The Program's mission is to foster national well-being and economic competitiveness by supporting university-industry collaboration to advance the Nation's technological leadership. According to the Engineering Research Center's Program Performance Indicators Data (2006), 41 ERCs have been funded since the Program's inception. The level of support is sizeable. For example, in the FY 2006 the NSF allocated $57 million to its ERCs ($1 million to $4 million per year per ERC). Since its beginning, ERC researchers have produced 13,391 peer-reviewed journal articles and 12,911 peer-reviewed conference proceedings. ERCs also have produced significant intellectual property; 1,431 inventions have been disclosed and 528 patents have been awarded to ERC researchers. Finally, ERCs have been the origin of 113 spin-off companies that employ 1,303 persons.

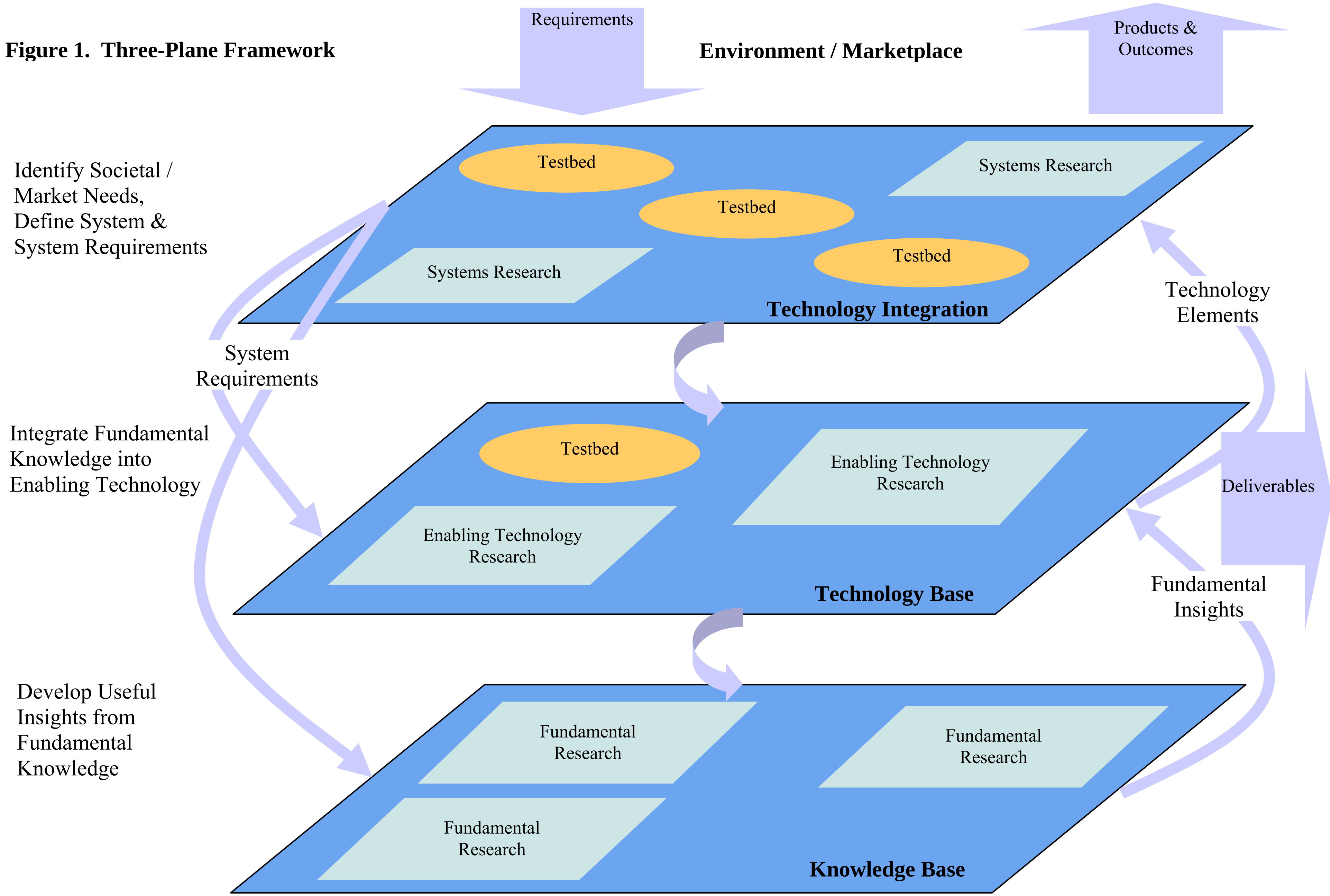
Another aim of ERCs is the education of science and engineering students. Specifically, ERCs are to produce baccalaureate and graduate degree recipients with distinctive skills and abilities that result from participation in ERC research. ERCs have graduated 10,694 bachelors, masters, and doctoral students. In addition, ERCs have been the source of 133 new degree programs, minors, and certificate programs and ERC-affiliated authors have written 193 textbooks.

The three-plane strategic planning framework was introduced in 1997 by the ERC Program's leader as a requirement for use in ERC strategic planning. The purpose of the three-plane framework is to promote future-oriented and innovative thinking in research planning endeavors, and to provide a tool for reporting the ERC strategic plan. Specifically, it requires ERCs to consider three levels of research: fundamental knowledge, enabling technology, and engineered systems. (See Figure 1 for a depiction of the three-plane framework). Another organizing tool required by the ERC Program is the milestone chart; the role of the milestone chart is outside the scope of the present study.

Often, ERCs amend their three-plane framework to include additional or fewer goals on each of the three levels, or even add additional levels to the framework. Each ERC's elaboration of the three-plane framework is an iterative process, working in conjunction with feedback from the ERC Program at NSF. Over time, each ERC's three-plane chart evolves as the center's goals and strategies evolve.

The three-plane framework is elaborated during the process of defining goals for the ERC. Two of these goals are research publications and application of research via technology commercialization. Because these two outcomes reflect the evolutionary progression from research discovery to tangible products/services, we emphasized them as organizational outcomes in the present study.

Figure 1. Three-Plane Framework



Contributions of the Study

To our knowledge, this study is the first of its kind to empirically analyze the organizational functioning of ERCs. Furthermore, our examination of organizational and management processes within ERCs is thematically akin to the NSF's attention to these factors in its Government Performance and Results Act (GPRA) Strategic Plan of June 5, 2003. In the GPRA Strategic Plan, the NSF included a focus on "organizational excellence in keeping with the belief that achieving NSF's mission is impossible without sustained excellence in NSF's business processes" (p. 5). Another benefit of this project is that our results may be used to develop programs for training ERC leaders about how further to improve the organizational functioning of ERCs. These training activities can serve as the basis for improved organizational and managerial techniques for enhancing the effectiveness of ERCs.

Scope of the Study

The present study focused on both predictors and outcomes of strategic planning within ERCs. Our aim was to explore generic patterns of strategic planning and related processes in ERCs.

Strategic planning takes place within the broader backdrop of the overall organizational functioning of ERCs. Therefore, we empirically studied the linkage between strategic planning and two organizational outcomes of ERCs: research publications and technology commercialization (i.e., research application). Furthermore, we investigated multiple antecedents of strategic planning. We also provide our recommendations regarding strategic planning and general management-related advice that we hope further improves the success of the overall ERC Program.

There are several boundary conditions of the study' namely, areas not included in the original proposal to the NSF and not addressed in our present research report. First, we did not conduct an evaluation study in which ERCs or ERC personnel were rated or ranked against each other or any other standard. Secondly, we did not rate or rank the leadership of individual ERCs. Third, we did not rate or rank ERC research quality or quantity. Fourth, we did not rate or rank strategic planning practices across ERCs. Fifth, the present study is not an in-depth analysis of industry partnering practices or ERC impact on society, and lastly, although ERCs are required to use milestone charts in their strategic planning activities, we did not examine their use in the present study.

Our study was funded by a peer-reviewed NSF grant (i.e., this study was not contract research). The authors do not have an employment relationship with the NSF. Although we consulted ERC Best Practice documents, our study was conceived and executed independently of these documents. No NSF funding decisions or funding recommendations will be affected by this study.

This project has been reviewed and approved by the Committees for the Protection of Human Subjects at both Rice University and the University of Houston. The informed consent letters stating the conditions agreed to by all participants are included in Appendix A. Individuals who participated will not be identified. No names of ERCs or individuals will be shared in this or any other report. The data we received from interviews and surveys were aggregated and identifying information was detached from individual responses to assure full confidentiality. All results are communicated in aggregate form. The NSF does not have editorial control over the results presented in this report. Feedback from the NSF will be invited, yet the authors retain final editorial control over the content of the report. The NSF, however, has full control over dissemination of our findings.

Theoretical Foundation for the Research

Theoretical Traditions in Extant Research Literature

Our study drew upon six areas of research literature. The first was strategic planning. Mixed findings concerning the benefits of strategic planning are common in the literature, especially when links to organizational outcomes are studied. However, the majority of scholars agree that formal or informal strategic planning has a positive impact on overall organizational effectiveness (Miller & Cardinal, 1994; Ramanujam, Venkatraman, Camillus, 1986; Reid, 1989; Veliyath & Shortell, 1993). The majority of the empirical studies on strategic planning and organizational effectiveness use financial performance measures to examine for-profit organizations. Therefore, the present study, with its focus on non-profit research organizations, makes a unique contribution to the current literature in strategic planning. In addition to organizational effectiveness, other outcomes of strategic planning have been found, including improved adaptability and integrative functions of planning (Ketokivi & Castaner, 2004), both of which apply to non-profit organizations as well. Overall, extant literature suggested that strategic planning is beneficial to organizations, but more needs to be learned about its benefits to research organizations.

The second area of literature on which we drew was research on organizational effectiveness. The best way to measure effectiveness is to use a mix of the goal and system resource approaches, or to use a multi-faceted approach (Banner & Gagné, 1995; Ostroff & Schmitt, 1993). Accordingly, the present study emphasized two types of outcomes in research organizations: research publication productivity and technology commercialization productivity. These describe two of the functions of modern research-oriented universities and university-based research centers (Shane, 2002).

Thirdly, we drew upon the literature concerning management of technology. Technology transfer effectiveness in universities has been frequently studied in recent years. Various organizational characteristics have been examined in current literature, such as organizational structure, geographic location, and proximity to industry, prestige and reputation of the institution and faculty, funding, and previous commercialization activities (Bozeman & Boardman, 2002; Di Gregorio & Shane, 2003; Shane & Stuart, 2002; Sine, Shane & Di Gregorio, 2003; Smilor, Dietrich & Gibson, 1993; Stuart, 2000). In our study, we considered individual attitudes toward planning as potential predictors of technology commercialization. These constructs have not been considered in the past and are potentially important antecedents to technology transfer effectiveness.

As a fourth step, we consulted the organizational structure literature. The organizational structure of ERCs varies in many ways; including the type of university in which they are based, the stakeholders involved, the level of hierarchy and formalization within the ERC, the type of research they pursue, and the domain of technology that they study. These facets have been shown to affect an organization's planning practices as well as criteria used to assess organizational effectiveness (Steenhuis & Gray, 2005).

Fifth, we examined the change management literature. Acceptance of new technology is commonly discussed simultaneously with resistance to change in organizational literature (Manz et al., 1990; Wilkinson, 1974). Individuals often express resistance by displaying behaviors meant to protect them from real or imagined outcomes of the change. In the case of academe, strategic planning and planning tools, such as the three-plane framework, are changes from conventional routines. Therefore, planning requirements are a potential threat to those who do not understand the reasons for change or are not accepting of it. For example, an academic researcher may see the imposition of a planning requirement as taking time away from research activities, especially if the researcher does not see a direct beneficial impact that planning might have on his/her research activities.

Finally, the organizational commitment literature was an important element of this study. Specifically, organizational commitment and professional commitment are two attitudes found in organizations that affect the degree of participation and acceptance of organizational policies and procedures (Porter, Steers, Mowday & Boulian, 1974; Tuma & Grimes, 1981). Organizational commitment is generally associated with increased effort by individuals to comply with organizational and administrative policies and procedures. Commitment is also linked with increased likelihood of organizational citizenship behaviors, in which employees participate in activities that are not in their job descriptions (Meyer, Stanley, Herscovitch & Topolnytsky, 2002). In the case of ERCs, planning requires organizational citizenship behaviors because the planning process is not directly associated with research or teaching. Conversely, professional commitment is more often associated with career success in one's profession or discipline rather than involvement in organizational processes. Typically, in organizations with highly educated workforces, professional commitment is the dominant form of commitment (Bline, Duchon & Meixner, 1991). ERCs are one such organization and, therefore, have a unique challenge of fostering commitment to planning processes while at the same time embracing the inherent levels of high professional commitment that are characteristic of academic researchers.

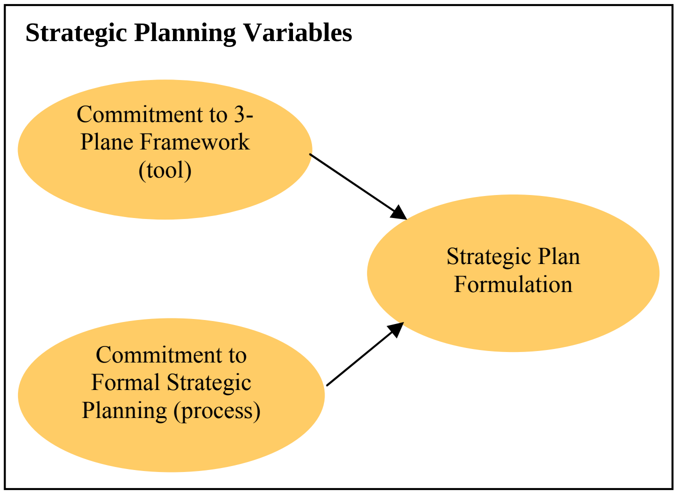
Theoretical Model

We tested a theoretical model derived from previous literature and our observations from interviews with ERC personnel. The model consists of three concepts: antecedents of planning, planning variables, and outcomes of planning. In total, we propose 11 hypotheses regarding relationships among these concepts.

Theoretically, only leaders are involved in planning in ERCs. However, through our interviews, we discovered that participation is much wider than just the leadership team. Therefore, our hypotheses concern all participating individuals in planning, which include faculty and even graduate students. We measured respondents' awareness of the three-plane framework and planning process in the survey to ensure only those who were familiar with these concepts were included in the final pool of responses.

Planning variables. Three factors central to strategic planning were explored: "commitment to the three-plane framework," "commitment to the formal planning process," and "strategic plan formulation." These are depicted in Figure 2.

Figure 2. Planning Variables



"Commitment to the three-plane framework" and "commitment to the planning process" are defined as the extent to which an ERC uses the planning tool (i.e., the three-plane framework) and a formal planning process, respectively. ERCs use the three-plane framework as a tool to help focus strategic planning and management to varying degrees. Further, ERC leaders in each center may pursue a more or less formal planning process. The tool and the process are distinct because an ERC may have high commitment to a formal strategic planning process, but disregard for the tool or vice versa.

Low commitment is characterized by minimal use of the planning tool and/or planning process. Conversely, high commitment is exemplified by maximal integration of strategic planning into the culture of the ERC.

Commitment to the tool and the process are illuminating concepts in ERCs because ERCs are required to use the three-plane framework to illustrate their strategic plan and have some form of strategic planning. Thus, all ERCs use the framework to some extent. However, commitment reflects the degree to which this is actually carried out. For instance, ERCs with low commitment to the three-plane framework, or to planning, will only minimally use the tool and/or process. These ERCs use the tool solely to comply with requirements of the NSF in order to continue receiving funding. Conversely, the ERCs with high commitment to the three-plane framework and/or the planning process integrated use of the tool and process into their culture. These ERCs have truly adopted a planning culture and understand the value it brings to their center.

High commitment to the planning tool and/or process was expected to lead to highly comprehensive planning. "Strategic plan formulation" describes the effectiveness and quality of planning, as well as the degree to which formal strategic planning occurs in an ERC; in other words, comprehensiveness of planning. Simply going through the motions of strategic planning may yield positive results, but not nearly those that can be achieved when the planning process is effective (Reid, 1989). Basic strategic planning has several potential benefits including adaptability, positive public relations, integrative functions, and organizational effectiveness (Ketokivi & Castaner, 2004; Miller & Cardinal, 1994; Ramanujam, Venkatraman & Camillus, 1986; Reid, 1989). However, if planning is comprehensive, it can have additional valuable outcomes including increased effectiveness and continued success of the organization. This continued success may occur due to increased adaptability and integration of the organization and its stakeholders, and shared vision among all parties. Therefore, it is important to understand how to achieve comprehensive strategic planning. Formally, we hypothesized the following:

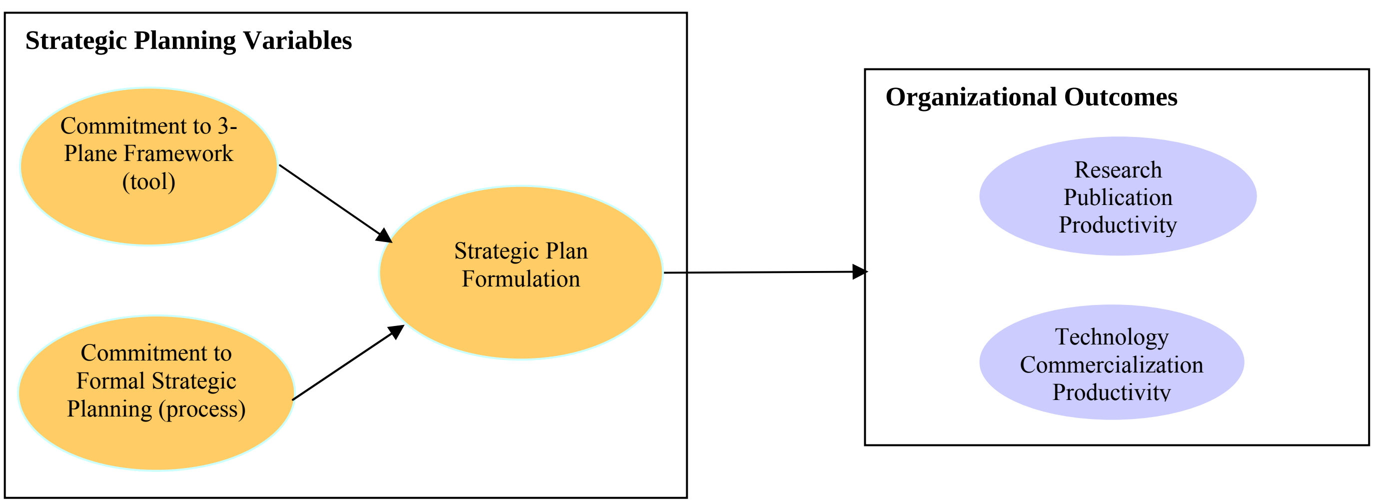
Hypothesis 1: A high level of commitment to the three-plane framework will be positively associated with strategic plan formulation.

Hypothesis 2: A high level of commitment to a formal process of planning will be positively associated with strategic plan formulation.

Outcomes of strategic planning. Strategic planning has many potential benefits; the most commonly studied are organizational outcomes such as effectiveness. Desired organizational outcomes are those which are defined in specific goals or are inherent in the mission of an organization. In line with the priorities of the ERC Program and with recommended ways of measuring organizational outcomes, our study explored two outcomes of ERCs: research publication productivity and technology commercialization productivity (Banner & Gagné, 1995; Ostroff & Schmitt, 1993). These reflect research progress in a center, in the form of knowledge dissemination and application of findings. Outcomes were measured using archival data from the ERC annual reports. Figure 3 depicts the model with the planning variables and their outcomes. We expected both outcomes to benefit from comprehensive strategic planning. We also expected commitment to the tool and process to promote desired organizational outcomes via their effect on strategic plan formulation. Formally, our hypothesis regarding planning outcomes is as follows:

Hypothesis 3: Formal, high quality strategic plan formulation will be associated with high levels of research publication productivity and technology commercialization productivity.

Figure 3. Outcomes of Strategic Planning



Antecedents of strategic planning. Eight antecedents of the planning commitment and strategic plan formulation were considered. Figure 4 depicts the model containing the eight antecedents and the planning variables.

Firstly, organizational commitment and professional commitment were explored as antecedents to both commitment to the planning process and commitment to the three-plane framework. Organizational commitment is the level of loyalty and obligation an individual feels towards the ERC. Professional commitment is the level of loyalty and obligation an individual feels toward his or her profession and personal career. Theoretically, individuals higher in their organizational commitment than their professional/personal commitment will be more likely to commit themselves to organizational processes such as planning. Organizational and professional commitment were the only two predictors considered for both commitment to the planning process and commitment to the tool. This was theoretically justified because they are strongly linked in the research literature with organizational processes such as planning.

In addition, six other antecedents were considered as predictors of commitment to the tool (i.e., three-plane framework). These antecedents were specific to the three-plane tool and, as such, were not considered as predictive of commitment to the process. Four were individual attitudes, including acceptance of the tool, perceived value of the tool, knowledge of the tool, and perceived capability of the tool to balance and rebalance resources in the ERC. Each of these reflect greater understanding and positive attitudes about the three-plane framework; therefore they should lead to greater levels of use of the three-plane framework, as captured by commitment to the tool.

We also explored two organizational characteristics of the ERC: time to commercializable product and technology domain. These were not measured by perceptions recorded in the survey, as the other antecedents were. Rather, in consultation with the ERC Program leadership, we categorized each ERC as to the amount of time to commercializable product and to technology domain.

Time to commercializable product is the length of the lifecycle of ERC research before a useful product can be handed off to industry. We expected longer lifecycles to commercializable product to increase the difficulty of defining engineered systems in the framework. This difficulty would make the task of filling out the three-plane framework more intellectually challenging. Therefore, ERCs pursuing this type of longer-term research may be less committed to use of the three-plane framework.

Technology domain represents the research sector of the ERC, namely biotechnology, manufacturing, earthquake, or information technology/electronics. In some of these fields, such as biotechnology and information technology, the number of potential engineered systems is vast, and these particular fields should also have a more difficult task of defining engineered systems. Although the originally defined engineered system goals are stipulated in the initial ERC proposals before funding is granted, revisiting these goals each year may prove difficult as research progresses in various potential directions. Again, this challenge may decrease a center's commitment to use the three-plane.

Our formal hypotheses relating to the eight antecedents are listed below, and Figure 4 summarizes these proposed relationships. The full hypothesized model is depicted in Figure 5.

Hypothesis 4: A high level of organizational commitment will be associated with high levels of commitment to the three-plane framework and commitment to the process of planning.

Hypothesis 5: A high level of professional commitment will be associated with low levels of commitment to the three-plane framework and commitment to the process of planning.

Hypothesis 6: A high level of acceptance to the three-plane framework will be associated with a high level of commitment to the three-plane framework.

Hypothesis 7: A high level of perceived value of the three-plane framework will be associated with a high level of commitment to the three-plane framework.

Hypothesis 8: A high level of knowledge of the three-plane framework will be associated with a high level of commitment to the three-plane framework.

Hypothesis 9: A high level of perceived capability of the three-plane framework to balance and rebalance resources will be associated with a high level of commitment to the three-plane framework.

Hypothesis 10: ERCs that pursue research with longer timelines to commercialization will be less committed to the three-plane framework.

Hypothesis 11: ERCs that pursue technology domains with a broad scope, leading to more possibilities of engineered systems, will be less committed to the three-plane framework.

Figure 4. Antecedents of Strategic Planning

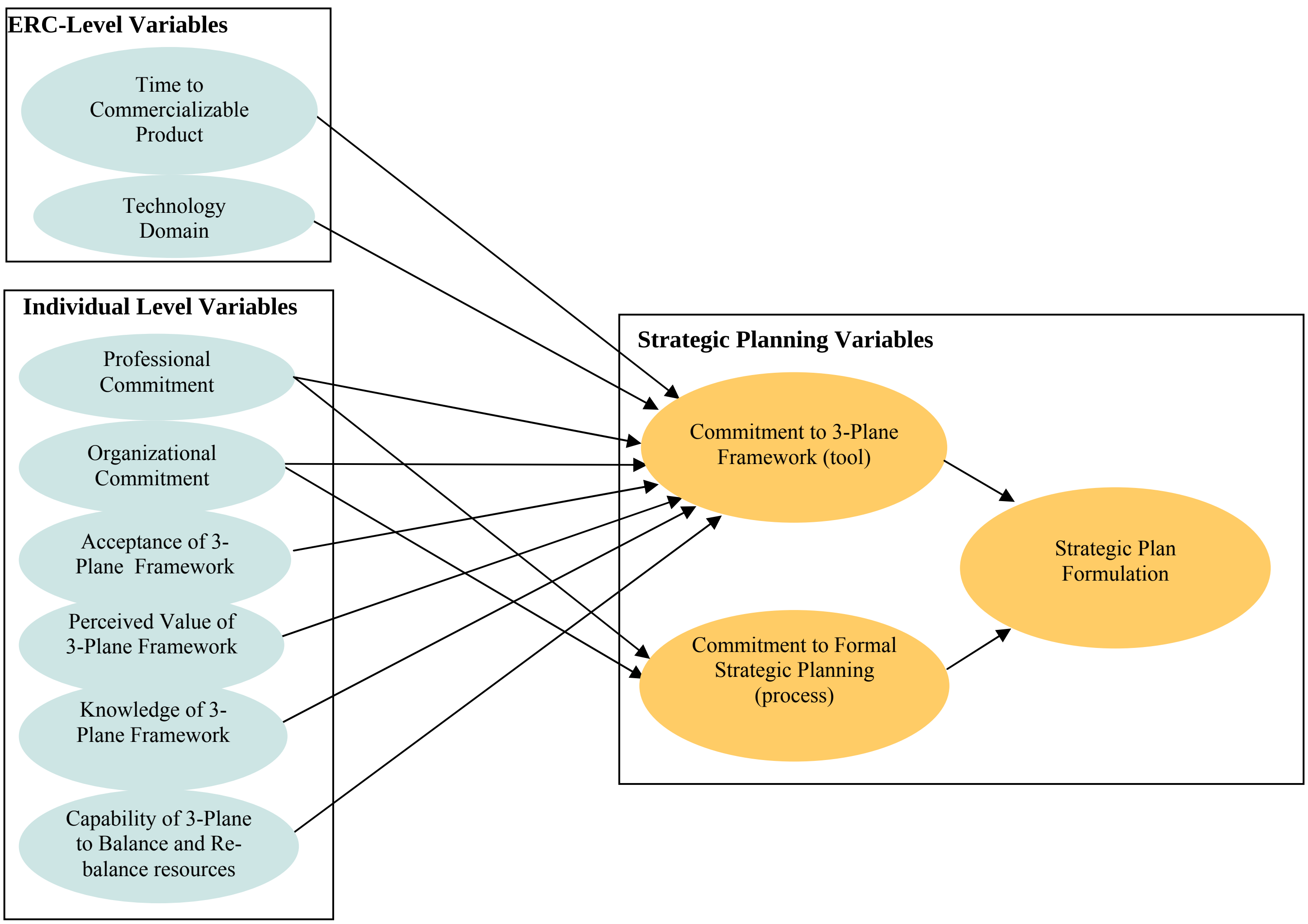
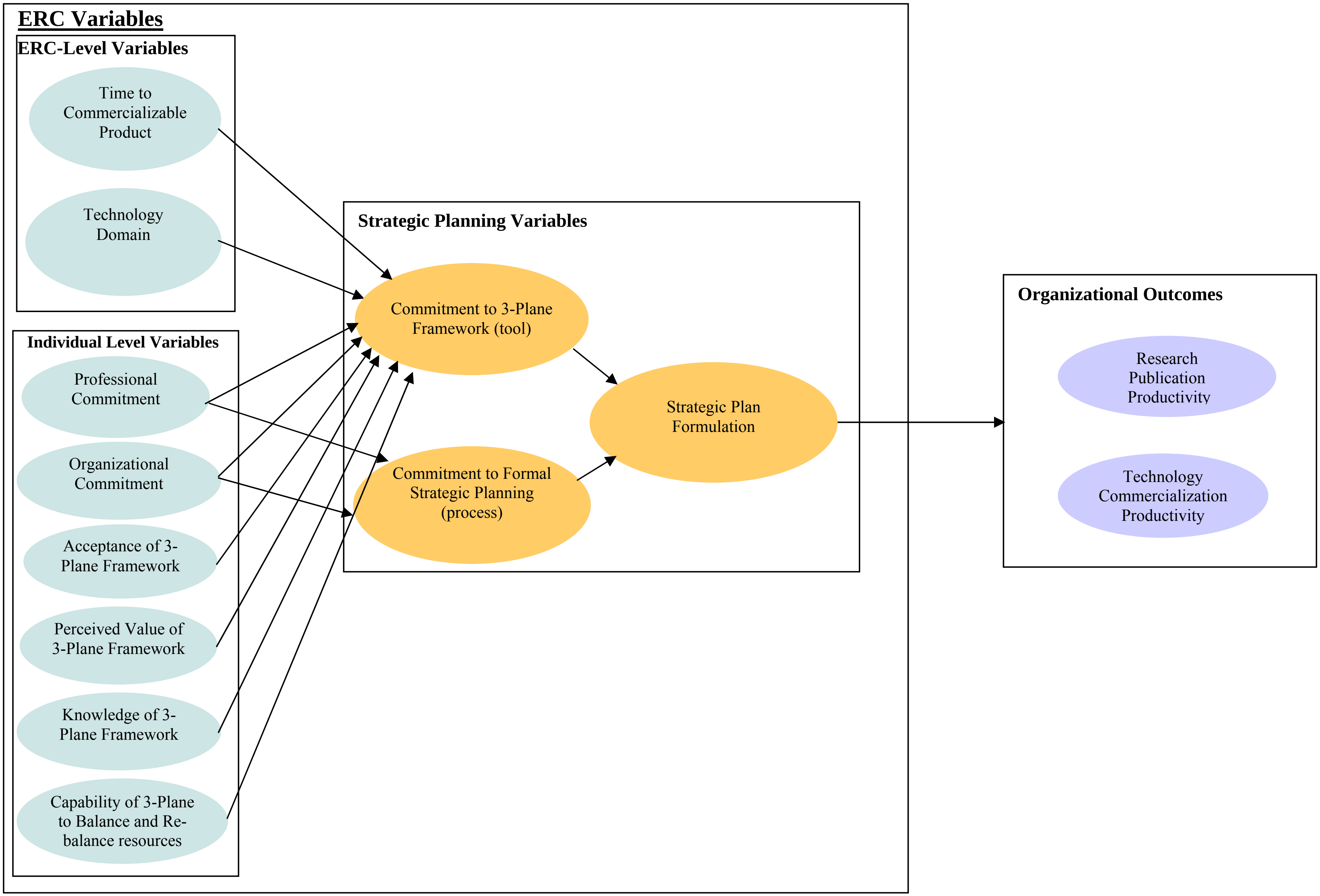


Figure 5. The Full Strategic Planning Model



Methodology

Philosophy of Science

We now provide a summary of how our research design accomplishes the five elements of a research project's "knowledge yield," as discussed in McCall and Bobko (1990) and Currall, Hammer, Baggett, and Doniger (1999).

Range of hypotheses. We have used a number of resources to develop our 11 hypotheses that address a wide variety of organizational phenomena in ERCs. First, by virtue of our qualitative data collection (i.e., interviews) during the past two years, we have become intimately familiar with the organizational functioning of ERCs. This familiarity has aided us in developing our hypotheses. Secondly, research literature in strategic planning, management of technology, and organizational effectiveness has informed development of our hypotheses.

Rigorous hypothesis tests. The combination of both qualitative and quantitative data positioned us to conduct rigorous tests of our ideas (Currall et al., 1999). Moreover, the quantitative techniques that we used, multiple regression, Poisson and negative binomial regression, and hierarchical linear modeling (HLM), are flexible analytical tools that permitted us to look at the data from many different angles. The rigor of these tools increased the likelihood that our results will stand up to scrutiny by other researchers and therefore contribute to a cumulative body of research literature on research productivity and technology commercialization productivity.

Detailed explanations. It should be emphasized that the tests of our hypotheses are, in a sense, only a point of departure for a deeper understanding of the relationships among constructs that we are investigating in this study. Detailed analyses of our hypothesis tests yielded new insights into the functioning of ERCs that we could not have conceived prior to conducting the research. Our analyses put flesh on the bones of the linkages that we posit in our hypotheses and help give meaning to our results.

Eliminating alternative explanations. We used statistical controls to understand and eliminate, the effect of variables that could potentially confound tests of hypothesized relationships. Multiple regression analysis, Poisson and negative binomial regression, and HLM are analytical techniques that afford statistical control whereby the researcher includes control variables in the test of the hypothesized model. The inclusion of control variables then permits the researcher to make statements about the nature of the relationship between the hypothesized independent and dependent variables after accounting for the effects of control variables.

Building a cumulative body of findings. Because our research on ERCs is the first of its kind, we focus much of our attention on communicating in significant detail about how we conducted the research, so as to permit other researchers to replicate our results and expand the knowledge base about ERCs. The use of standardized statistical techniques also fosters the development of a cumulative body of findings because results across studies can be compared.

Causation. The analyses performed here are rigorous and complete for the reasons listed above. Without longitudinal outcomes and predictors, however, no study can make inferences about causation. It is possible that relationships among variables are unidirectional (even the opposite of the hypothesized direction) or reciprocal. Therefore, because we use cross-sectional predictors in this study, we acknowledge that the results we report are associations; the true order of causation must be established using longitudinal methods.

Methodological Procedures

Data collection. Data were collected from three sources: archival data, interviews, and surveys. See Table 1 for a summary of the types of data collected, and the levels of measurement and analysis of each. By "levels of measurement", we mean the level at which the data were collected. Individual-level measurement refers to data collected about individuals, which included archival, interview, and survey data collection. ERC-level measurement refers to ERC categorizations and ERC archival data from annual reports. "Levels of analysis" refer to the level at which the data was statistically analyzed. We analyzed data at the original level it was collected (i.e., both individual- and ERC-levels). We also aggregated all individual responses to ERC averages to analyze relationships between organizational outcomes and the planning variables. See Appendices E and F for specific details on measurement and analysis.

Table 1: Types of data collected

Type of Data	Level of Measurement	Level of Analysis	Use of Data
Archival	ERC and Individual	ERC and Individual	Organizational outcomes of planning; Organizational characteristics
Interview	Individual	Individual	Context to generate hypotheses, survey, and explanation of findings
Survey	Individual	ERC and Individual	Planning variables; Antecedents of strategic planning

Each year, all ERCs must report their resource (e.g., financial) and performance data to QRC, which is a company with whom NSF contracts to collect, organize, and analyze ERC data. For our study, we collected archival data from QRC for all 22 active ERCs when the study began. Each ERC submits its data via ERCweb. QRC provided these data directly to us. We also received paper or electronic copies of the full annual narrative reports submitted to the NSF each year by all ERCs. Together, these data provided the organizational outcome indicators and they also added to our contextual knowledge regarding the activities, resources, personnel, and performance of each ERC.

Our interviews were conducted between January 2005 and September 2005. These interviews allowed us to gain in-depth knowledge of the context of ERCs; hypotheses and the survey instrument were derived from the interview data. Further, interview data was used to interpret many of the quantitative findings once analyses were complete.

The director and/or industrial liaison from every ERC was interviewed in person or by phone. Additionally, eleven ERCs were chosen for in-depth, face-to-face interviews based on their geographic location and their willingness to host this study's researchers for one to two days. Some of the directors of the selected ERCs accepted invitations to serve on a technical advisory board for this project. During each ERC interview visit, a wide variety of individuals were interviewed, including members of the leadership team (i.e., directors, assistant directors, industry liaisons, educational/outreach officers), research thrust leaders, general faculty, administrative staff, and graduate students. Interviews took place one-on-one or in groups, as appropriate. Each interviewee was reminded that confidentiality would be maintained throughout the study. They were assured that only aggregated results would be shared at the completion of the study, and no individuals would be identified. These three statements served to put the participants at ease and encourage them to respond honestly to the questions. The full list of interview questions is presented in Appendix B.

Upon completion of the interviews, we developed hypotheses and created a survey instrument consisting of about 150 items. The survey was piloted during October 2005. A NSF-funded university-based research center participated in the pilot. Although not technically an ERC, this center functions very similarly to ERCs and is required by NSF to use the three-plane framework. Therefore, this center was an ideal candidate for the pilot test. The survey was administered online via Surveymonkey.com. After responses were received, a focus group was held to discuss reactions to the survey and its items. The pilot survey was edited and finalized based on this focus group feedback. Approximately 30 responses to the pilot survey were also factor-analyzed, and internal consistency reliability in the form of Cronbach's alpha was calculated (Cohen, Cohen, West & Aiken, 2003) for each survey scale. The items that did not load consistently or reliably on the intended constructs were dropped from the original pool of 150 items.

The revised survey was administered to all ERCs during November and December 2005 via the same online survey tool. The survey consisted of approximately 120 items and required 15 to 20 minutes of each participant's time. The participants were notified at the annual ERC conference and also by email when the survey was posted. They were asked to complete the survey within one month. Three reminder emails were sent out after the survey had been online for one, two, and three weeks, respectively. Approximately 2300 participants were asked to complete the survey; 839 participants responded, representing a 37% response rate. After data cleaning, 380 respondents remained in the final sample. The demographics of the final sample are presented in Table 2.

Table 2: Demographics of survey respondents

Table 2a. **Demographics: Gender and Ethnicity**

Gender	**Number**	**Percentage of total respondents**
Male	285	75%
Female	95	25%
Ethnicity	**Number**	**Percentage of total respondents**
African-American	10	2.6%
Asian or Asian-American	65	17.1%
Hispanic	23	6.1%
Native American	1	.3%
White/Caucasian	267	70.3%
Other	14	3.7%

***Table 2b.* Demographics: Titles and Roles**

Title within university	Number	Title within university	Number
Assistant Professor	31	Department Chair or Dean	12
Associate Professor	58	Administrative Staff	40
Full Professor	98	Research Scientist	23
Endowed or Named Professorship	24	Research Support Personnel	12
Emeritus Professor	4	Postdoctoral Researcher	10
Adjunct Professor	2	Graduate Student	84
Visiting Professor	2	Undergraduate Student	6
Lecturer	6	Other	30
Role within ERC	**Number**	**Role within ERC**	**Number**
Director	18	Other Leadership Role	28
Assistant Director	27	General Faculty Member (no leadership role)	81
Administrative Director	18	Support Staff	14
Industrial Liaison Officer	15	Postdoctoral Researcher	10
Educational/Outreach Director	20	Graduate Student	85
Testbed Leader	14	Undergraduate Student	5
Thrust Leader	45	Other	51
Project Leader	68		

***Table 2c.* Affiliation with ERC**

Affiliation status	Yes	No
Individuals who sought out affiliation with their ERC before they joined it	79[a]	232[a]
Before the individual joined their ERC, representatives from the ERC sought them out to join	205[a]	108[a]
Employed by Lead University of ERC	244 (64%)	136 (36%)
Currently Involved with ERC	357 (94%)	23 (6%)
Alumni but not currently involved	17 (4%)	363 (96%)
With ERC when it started	181 (48%)	199 (52%)

Note. [a]Percentages are not reported because missing data on these two items prevent inferences from percentages (N=311 and 313, respectively).

Measurement of Variables. All individual attitudes and perceptions were measured using survey responses. These included the three planning variables (i.e., strategic plan formulation, commitment to the tool, and commitment to the process) and six of the antecedents of planning (i.e., organizational commitment, professional commitment, acceptance of tool, perceived value of tool, knowledge of tool, and perceived capability of the tool to balance and rebalance resources). The full survey is included in Appendix C.

The two other antecedents of planning were organizational characteristics (i.e., time to commercializable product and technology domain). “Time to commercializable product” was assigned a value of ‘0’ for pre-paradigmatic centers, or those with a long time to commercializable product. A value of ‘1’ was assigned for paradigmatic centers, or those with a shorter time to commercializable product. These designations were provided by the ERC Program leadership at NSF. Technology domain was assigned a nominal-level values of 1 through to 4 and was defined using an NSF listing of current ERCs categorized into one of four research domains (National Science Foundation, 2005): biotechnology ('1'), manufacturing ('2'), earthquake ('3'), or information technology and electronics ('4').

Organizational outcomes were measured using annual reports of 22 ERCs from 2001 through 2005. Two outcomes were considered. First, research publication productivity included a number of publications in peer-reviewed academic journals and conference proceedings. Second, technology commercialization productivity included the number of invention disclosures, patents filed, patents awarded, licenses, spin-offs (number of companies and number of employees), and new standards created (e.g., construction and building code standards). We analyzed these two outcomes as well as each of their components individually to fully understand the relationship of planning and organizational outcomes.[1]

Statistical Analyses. We employed five statistical analyses in this study: confirmatory/exploratory factor analysis, hierarchical linear modeling (HLM), ordinary least squares regression, Poisson regression, and negative binomial regression. Confirmatory and exploratory factor analyses were conducted on the survey data in order to ensure that the survey items accurately represented the constructs they were intended to measure.

HLM is a statistical technique designed for data that contains individual participants clustered in groups (i.e., the 22 ERCs represent 22 groups of participants). It maintains the hierarchical structure of the data and, accordingly, compares not only across individuals, but also individuals within ERCs and across ERCs. We used HLM to analyze relationships between the antecedents of planning and the planning variables (Cohen et al., 2003; Hofmann et al., 2000).

Ordinary least squares, Poisson, and negative binomial regression were used to analyze relationships between the planning variables and the outcomes of strategic planning. (HLM cannot be used for the analyses involving organizational-level effectiveness; it requires that the outcome variable is measured at the lowest level of analysis, which in this case was the individual-level [Hofmann et al., 2000]). Also, the outcome variables in these analyses were counts (i.e., number of publications, licenses, etc.), for which Poisson and negative binomial regression were appropriate. Ordinary least squares regression was used to analyze the relationships between the commitment to planning variables and strategic plan formulation because these were continuous ordinal-level variables.

The use of a combination of statistical techniques allowed us to analyze the data from a variety of angles to ensure that our results are robust and defensible. The use of the five statistical techniques also fosters the development of a cumulative body of findings because results of our study can be compared with others. See Appendix E for a report of the technical aspects of analyses used in this study.

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[1] Further analyses were also performed on each technology commercialization outcome separately. Detailed results are available from Sara Jansen Perry (skjansen@uh.edu).

Results

Key Qualitative Findings

In this section, we share the primary findings we gleaned from the interviews concerning strategic planning. Key themes are our inferences based on input from a variety of ERC personnel and observations during our visits to the ERCs.

When new ERCs are founded, they have often used a general three-plane framework in their grant proposal to present their strategic plan. Shortly after founding, new ERCs spend a full day with the ERC Program leadership, to learn about responsibilities of center management, financial management, reporting, and strategic planning. As an ERC evolves, it periodically submits a revised three-plane framework, presenting a revised strategic plan to the NSF Program for review and comment. Therefore, the three-plane framework and the strategic plan are living documents that evolve with the ERC. The overall intent of the three-plane framework is to provide an organizing format that helps an ERC do strategic planning and that reflects the three levels of activities (i.e., fundamental research, enabling technologies, and engineered systems). The development of the three-plane framework is meant to be flexible and therefore useful to all types of ERCs.

Based on our qualitative data, we concluded that the three-plane framework is a useful tool for ERCs. The framework provides a conduit for thinking about the connection between academic science and engineering research and products that have a beneficial impact on society. The framework is the tool used by the ERC Program to ensure the relevance of the research to society as a whole. This is important because societal tax revenue provides the funding source for NSF and the ERC program in particular. Furthermore, the framework provides a theory for developing a “dashboard” showing progress toward achieving engineering research goals. Our quantitative results, discussed in a later section, substantiate this conclusion.

Because the ERC strategic planning processes and use of the three-plane framework was the primary focus of our study, we received substantial feedback on these topics. Four categories of feedback emerged: (1) heterogeneity in approaches to planning, (2) one-size-fits-all models of planning, (3) acceptance of planning, and (4) areas that could be improved.

Heterogeneity in approaches to planning. We uncovered a number of sources of heterogeneity determining the particular model of planning used by ERCs. Specific usage patterns of strategic planning and the three-plane framework varied depending on the planning approach adopted.

First, most ERCs viewed strategic planning and the three-plane framework as valuable. Many ERCs used the three-plane framework in their initial proposals to the ERC Program. The leaders of these ERCs had familiarity with strategic planning, either through experience in industry or leadership development and self-education. Due to these broad perspectives, these leaders found value in top-down planning of the research endeavor. They also became champions of planning and the three-plane framework in their conversations with faculty members within the ERC.

Second, a number of ERCs viewed strategic planning as useful but found modest value in the three-plane framework. Those ERC leaders were similar to the first category in their exposure to strategic planning, but often were still learning how to best use the three-plane framework in planning. Therefore, we believe that any lack of acceptance to the three-plane framework often came from lack of understanding of its purpose and use. However, ERC leaders usually gained more appreciation for this planning tool as they learned more about its purpose and intended use and value.

Finally, a number of ERCs placed more emphasis on curiosity-driven research. Some of these ERCs did only the minimum required to adhere to the ERC Program requirements for planning. Some leaders of these ERCs did not involve faculty in the planning process or in use of the three-plane framework. Most faculty in these ERCs, therefore, were not very aware of the three-plane framework.

One-size-fits-all models of planning. A one-size-fits-all approach to use of the three-plane framework was not appropriate, primarily because of the diversity of ERCs. Flexibility was desirable in implementation of the three-plane framework, especially in the engineered systems plane. For instance, some ERCs had broader ranges of engineered systems and found it difficult to accurately and specifically define an engineered system goal. Some variations of the three-plane framework have been utilized in ERCs to address unique needs and requirements. In Appendix D, we have provided examples of creative solutions used by ERCs to organize their research endeavor.

Another area of required flexibility was the timeline of ERCs. Life sciences, for example, is a field that often needs longer than 10 years to create engineered systems and technologies that are useful for industry. The ERC Program may wish to consider urging new ERCs in life sciences to advance their research further before requesting funding from the ERC Program. This would allow ERCs that are creating entirely new fields to achieve useful discoveries by the time they graduate from the ERC Program. Alternatively, another type of NSF-funded research center, such as one focused on fostering interdisciplinary research at the very early stages of basic science, also would be appropriate as a precursor to entry into the ERC Program.

Acceptance of planning. We uncovered a number of themes relating to levels of acceptance of and resistance to the three-plane framework. We heard positive feedback indicating that acceptance exists across many ERCs. Many interviewees commented that the three-plane helped them organize the ERC and operations within research thrusts. Others said it helped them organize the overall mission of the ERC. Also, the three-plane framework was useful in avoiding distractions of other types of technologies that could be funded yet, were not core to the mission of the ERC. Some recognized the three-plane as a tool that helped allocate resources. It also helped ERC personnel communicate the usefulness of their work (e.g., communicated through "deliverables" on the right side of the three-plane chart). Therefore, much positive sentiment exists in relation to the three-plane framework.

As stated previously, for an ERC to fully embrace the three-plane, it needs a champion. This is a person who fully understands the value of the three-plane and can communicate it to others. If the ERC director was a vocal champion, then the rest of the ERC tended to reflect a supportive culture surrounding strategic planning and the three-plane framework.

Typically, when the director or other ERC staff members did not fully understand and communicate the value of the three-plane framework, little use of the framework took place. In these cases, a pre-existing research plan was retrofitted into the three-plane chart and no real changes in future-oriented thinking occurred. The framework was used primarily for communication to the NSF. This phenomenon was reminiscent of the institutional theory of decoupling, put forth by Meyer and colleagues (e.g., Edelman, 1992; Meyer & Rowan, 1977; Meyer & Scott, 1983). Decoupling occurs when flexibility is given in the interpretation of organizational requirements. Specifically, government-regulated organizations often publicly comply with the regulations, but in reality, requirements are implemented much more loosely within the organization. Such decoupling was exhibited by ERCs that use the three-plane framework mainly for reporting purposes; they comply with NSF regulations but under-utilize the three-plane framework as a guide to their operations. Yet, when the three-plane had a champion who was successful in communicating its value, significant changes in operations occurred. Through use of the three-plane framework, ERCs often came away with an entirely new way of approaching research planning.

Areas of improvement. We found two areas of potential improvement: communication and expectations. First, some perceived the language used to present and describe the three-plane framework as being industry-oriented. Therefore, the knee-jerk response of academic researchers was to resist. Industry-oriented language was seen by some as incompatible with the developmental lifecycle of academic research in which failure does not exist, only redirection. If the three-plane framework and the process of strategic planning were presented in a way that emphasized a continually-evolving process rather than a development project in industry, more acceptance may ensue.

Some ERC personnel expected that the three-plane framework was intended to be the end-all solution to success as an ERC. However, the ERC Program emphasized that it is simply a tool to help define and organize future goals. Furthermore, there was occasionally a misguided perception that the three-plane aims to replace the natural creative processes of scientists. In reality, this creative process generates emergent strategy (Mintzberg, 1994), which is distinct from strategy formulated in formal strategic planning sessions. Both types of strategy are important and, therefore, the natural creative process of scientists should be nurtured in addition to formal planning. It was not the NSF's intent to replace the natural idea-generation of scientists by introducing the three-plane framework. The ERC Program leadership understands that three-plane framework is good for coordinated planning yet cannot take the place of the natural creative instincts of scientists. The creative skill of a scientist and/or engineer must be taken as a given and the three-plane framework should work in concert with this.

Later, we provide a formal Recommendation section in which we highlight the most important strategic planning best practices and suggestions based on both our quantitative and qualitative findings.

Key Quantitative Findings

Attitudes and organizational outcomes in ERCs. Table 3 provides means and standard deviations of all variables. Attitudes were measured with an online survey in 2005, using a 7-point scale, with '1' indicating the lowest level of the attitude and '7' indicating the highest level of the attitude (e.g., low or high commitment to the planning process). A value of '4' is neutral. The standard deviation indicates the typical variation on the 7-point scale. Research publication and technology commercialization outputs are from the 2005 ERC annual reports. The composite variables are an average of the indicators they represent.

One interesting comparison was between organizational commitment and professional commitment. Although, as expected, professional commitment is higher than organizational commitment (means are 6.12 and 5.23, respectively), the discrepancy is not as great as we anticipated. We believe this was due to the integrative effect of strategic planning (Ketokivi & Castaner, 2004). In other words, the process of strategic planning may have served to unify an ERC. Through the increased communication and involvement of personnel in applying the three-plane framework, the organizational commitment of ERC personnel may have been increased in an otherwise highly professionally-committed workforce.

Table 3: Descriptive Statistics of Study Variables

Variable name	Mean	Standard deviation
Average Yearly Research Publication Outputs (Composite)	23.51	19.57
Average Yearly Technology Commercialization Outputs (Composite)	2.24	3.14
Invention Disclosures[a]	6.25	7.22
Patent Applications[a]	4.63	5.12
Patents Awarded[a]	1.44	1.98
Licenses[a]	2.43	4.62
Spin-off Companies[a]	0.32	0.43
Spin-off Company Employees[a]	4.90	14.25
Building Codes Impacted[a]	0.01	0.05
New or Impacted Technical Standards[a]	0.05	0.21
New Medical Standards[a]	0.11	0.47
Technical Journal Publications[b]	26.68	18.32
Peer-Reviewed Journal Publications[b]	2.61	5.38
Conference Proceedings[b]	41.23	45.90
Strategic Plan Formulation[c]	5.57	1.04
Professional Commitment[c]	6.12	.70
Organizational Commitment[c]	5.23	1.13
Commitment to the Three-Plane Framework[c]	4.76	1.16
Commitment to the Planning Process[c]	5.10	1.27
Acceptance of the Three-Plane Framework[c]	4.60	1.26
Perceived Value of Three-Plane Framework[c]	4.72	1.23
Knowledge of Three-Plane Framework[c]	4.75	1.53
Perceived Capability of Three-Plane Framework to Balance and Rebalance Resources[c]	4.63	1.34

Note. [a]Indicators comprising technology commercialization composite variable (n=22); [b]indicators comprising research publications composite variable (n=22); [c]attitude variables measured on a 1-7 point Likert scale (n=380).

Planning Variables

Commitment to the three-plane framework. Regression results indicated that five antecedents as positively associated with commitment to the three-plane framework: professional commitment, acceptance of the three-plane, perceived value of the three-plane, knowledge of the three-plane, and perception of the ability of the three-plane to balance and rebalance resources.

First, individuals who are highly committed to their profession were more committed to the three-plane framework. We believe this was due to the focus of the three-plane on organizing research, rather than on administrative and operational issues of the ERC. Secondly, individuals who accepted the three-plane instead of resisting it and who saw it's value for use in strategic planning, were more highly committed to it. Third, individuals who felt they understand and know how to use three-plane were more highly committed to it. Finally, individuals who believe that the three-plane helped allocate and balance resources across the ERC were more committed to it. Of these, knowledge of the three-plane had the strongest association with commitment to it. This implied that education was very important for ERCs to embrace this planning tool as a part of their planning culture.

The overall value that an ERC as a whole places on the three-plane framework also emerged as an important determinant of commitment to the three-plane framework. Therefore, it is not only the individual's attitude, but also the culture of the ERC regarding the three-plane's value that strongly impacted whether the three-plane framework was integrated into the planning process.

Interestingly, technology domain of the ERC and time to commercializable product were not related to the level of commitment to the three-plane framework. We originally hypothesized these relationships based on the difficulty ERCs have in defining engineered systems on the third plane of the framework. But this finding implies that the level of difficulty in defining the third-plane (i.e., engineered systems) does not affect how much the ERC will use the three-plane framework (i.e., for an annual reporting exercise or true strategic thinking).

Commitment to the process of strategic planning. We were also interested in what factors increase the level of commitment to the general process of strategic planning in ERCs. Only organizational commitment was associated with commitment to the process. This was not surprising because the process of planning is highly administrative and organization-focused. Therefore, those more highly committed to the ERC were more likely to commit to the process of planning, which included dedicating time to a formal process of planning and acknowledging the usefulness of formal planning activities. Professional commitment was not related to commitment to the planning process.

Strategic plan formulation. Regardless of the method used to plan, an important consideration is whether planning in general occurs and whether it is comprehensive, effective, and produces high quality plans. Five variables significantly affected strategic plan formulation: (1) commitment to the three-plane, (2) commitment to the process of planning, (3) commitment to the ERC, (4) perceived capability of the three-plane to balance and rebalance resources, and (5) knowledge of the three-plane framework.

First, the general culture in the ERC regarding commitment to the three-plane in an ERC was negatively associated with strategic plan formulation. This may suggest the possibility that some ERCs placed an over-emphasis on the mechanics of "how to" use the three-plane framework rather than considering the overall issues and goals of the ERC. Second, commitment to the process of planning was positively associated with strategic plan formulation, suggesting that an ERC culture committed to some form of planning leads to comprehensive planning.

Third, organizational commitment, which reflects commitment to the ERC itself, was positively associated with strategic plan formulation. This was not surprising because planning is an organization-focused process and requires commitment to the ERC for time to be devoted outside of core academic job activities. Fourth, whether the tool was perceived to balance and rebalance resources was positively associated with strategic plan formulation. This perception may have affected the extent to which ERCs use the three-plane for real planning and, therefore, how comprehensive the planning is overall. Further, a major component of planning is strategic allocation of resources. So, if the planning tool is capable of aiding with this task, it may help the planning be more comprehensive. Although the three-plane framework was not implemented for purposes of resource allocation, we found that many centers used it for that purpose in addition to presenting their strategic plan. Fifth, knowledge of the three-plane was positively associated with strategic plan formulation. This again highlights the importance that knowledge of the planning tool has in the success of the overall planning process.

In addition to these variables that were directly associated with strategic plan formulation, three other variables had an effect on planning indirectly via commitment to the three-plane: professional commitment, acceptance of the three-plane, and perceived value of the three-plane framework. All were positively associated with commitment to the three-plane, which was negatively associated with plan formulation. This suggests that although they help raise commitment to the tool, they indirectly have a negative impact on plan formulation. Again, this effect may be explained by an overemphasis by some ERC personnel on the minutiae of how to use the tool rather than on the overall goals and mission of the ERC.

The results discussed above refer only to those of the multi-level model, which tested the effect of variables at the level of measurement (i.e., individual attitudes were analyzed at the individual level). The results are summarized in Figure 6. Statistically significant effects are designated by the direction of the effect only; actual statistical coefficients are not depicted here but are provided in Appendix F.

Outcomes of Strategic Planning

Research publication productivity. Research publication productivity reflected the number of overall publication outputs achieved by the ERC. At the composite level, research publication productivity was not affected by any planning variables. As for the individual components of research publications productivity (types of publications considered), none were significantly impacted by planning either.

This may indicate a lack of focus on these types of outputs during the planning process and in using the three-plane framework. Indeed, these were not explicitly addressed by most ERCs anywhere in the planes of the three-plane chart, as it focuses primarily on the furthering of technology and research advances captured by the technology commercialization productivity. Further, the intention of the three-plane framework was not to define goals for research publications. Hence, this finding indicates that in order for a certain type of effectiveness to be impacted by planning, it must be an explicit priority in the planning process.

Technology commercialization productivity. The level of technology commercialization productivity reflected the number of technology transfer outputs of the ERC. This indicator was analyzed both as a composite of all technology transfer outputs and by analyzing each individual component. Composite technology commercialization productivity was positively associated with strategic plan formulation, indicating that strategic planning benefited this type of outcome.

However, technology commercialization productivity was negatively associated with commitment to the process of planning. When both strategic plan formulation and commitment to the process were analyzed, their unique influences on effectiveness were taken into consideration; therefore, it may be that plan formulation reflects the true output and content of planning rather than the steps and "how to" of planning. Conversely, commitment to the process may reflect an overemphasis on the steps and requirements involved in formal strategic planning, without sufficient focus on the overall intent of planning. Also of note, technology commercialization productivity was not directly associated with commitment to the three-plane framework. In other words, the extent of use and integration of the three-plane framework into ERCs' planning cultures had no direct effect on technology commercialization productivity. Instead, commitment to the three-plane framework exhibited an indirect negative effect via strategic plan formulation.

Most individual components of technology commercialization productivity showed identical results as the composite indicator, including invention disclosures, patents awarded, and licenses. The only exception was new medical standards, which was positively associated with commitment to the three-plane and commitment to the process, but was not related to plan formulation. This result may be biased because of the small number of medical standards in the data. However, if it is to be taken as accurate, it may indicate that those ERCs producing medical standards benefited from using both the three-plane framework and a formal planning process.

The results discussed above refer to the planning variables and the organizational outcomes variables at the ERC-level model only. A summary of the ERC-level findings are depicted in Figure 7. In this model, individual-level attitudes were aggregated to the ERC-level, ignoring within-ERC variance. Later, we elaborate the distinction between the multi-level and ERC-level models.

In summary:

Hypothesis 1: was not supported, as commitment to the three-plane negatively impacted strategic plan formulation.

Hypothesis 2: was supported, as commitment to the process positively impacted plan formulation.

Hypothesis 3: was partially supported, because research publication productivity was not impacted by strategic planning. Yet, technology commercialization productivity was positively impacted by plan formulation.

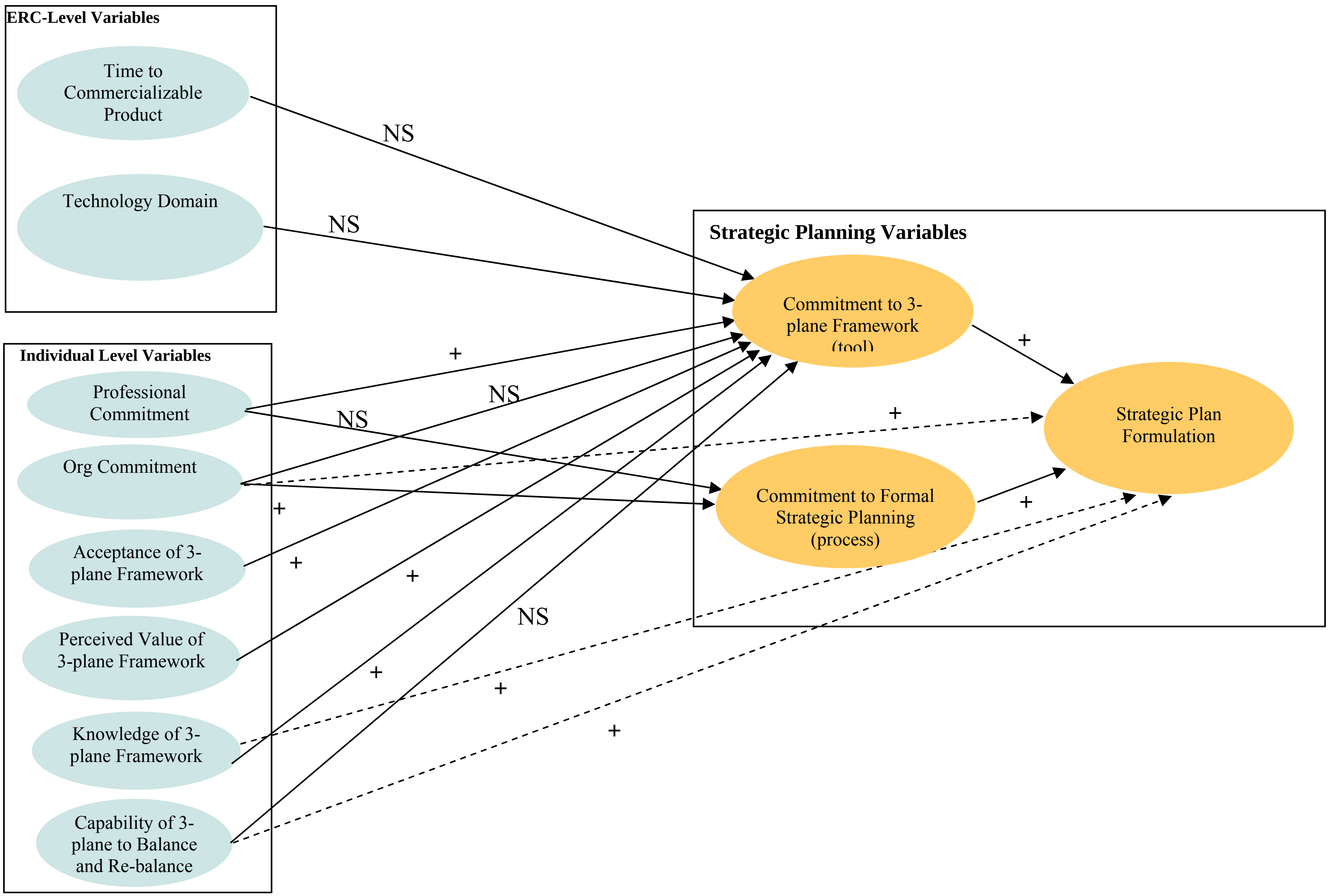
Hypothesis 4: was partially supported, as organizational commitment was associated with commitment to the process only.

Hypothesis 5: was not supported, but professional commitment was significantly and positively associated with commitment to the tool.

Hypotheses 6, 7, 8, and 9, which pertained to the individual-level attitudinal antecedents of commitment, were fully supported.

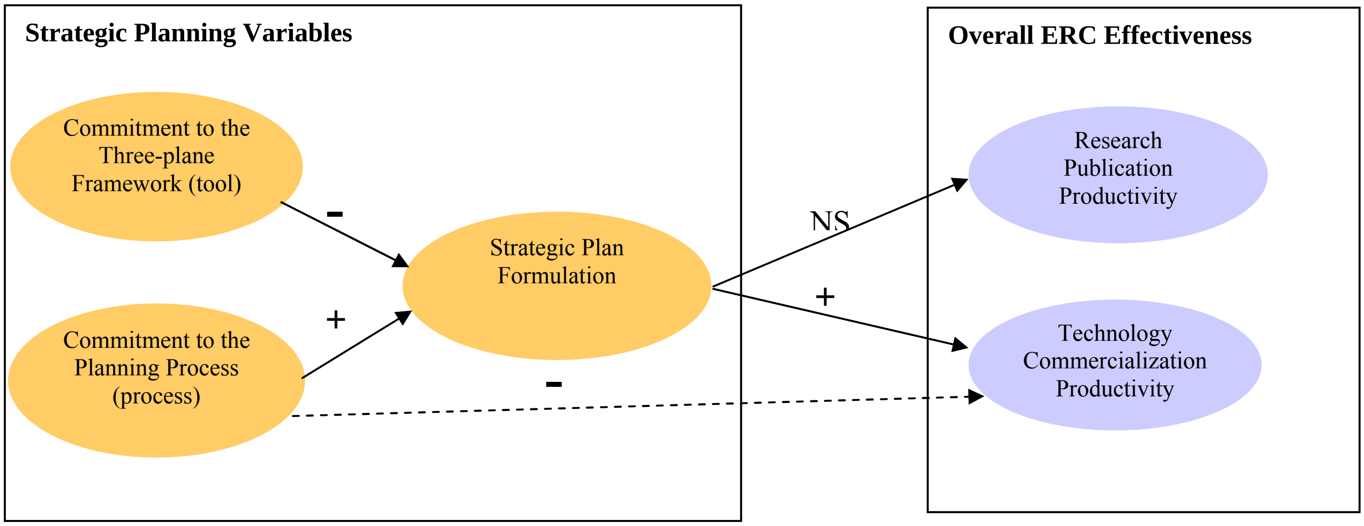
Hypothesis 10 and 11: which involved the ERC-level antecedents of commitment, were not supported.

Figure 6. Multi-level Model Results



Note. '+' indicates direction of significant effect at $p < .05$. 'NS' indicates non-significant effect. Dashed lines indicated unhypothesized direct effect.

Figure 7. Results of ERC-level Model



Note. + and – indicate direction of significant effects at $p<0.05$. Dashed line indicates un-hypothesized direct effect. NS indicates non-significant path.

Two findings warrant further discussion. First, the sign of some coefficients differed depending on the model tested. In the model that tested the antecedents of commitment and plan formulation (Figure 6), the impact of commitment to the three-plane framework on planning was positive. This model was a test of the effect of individual attitudes (i.e., a *multi-level* model taking into account both variance of individual attitudes within ERCs and variance across ERCs).

However, a separate *ERC-level* model (i.e., model that tested aggregated individual attitudes in the ERC; Figure 7) tested the impact of commitment and planning on organizational outcomes. In the ERC-level model, the impact of commitment to the tool on planning was negative.

Contrary to the multi-level model, the ERC-level model was a test of aggregated attitudes in the ERC only, ignoring individual variance of attitudes within ERCs. In other words, the variables in the ERC-level model reflected the average culture of the ERC with regard to commitment and planning. Therefore, the results of the ERC-level model imply that an ERC whose culture is too attentive to adhering to the details of the three-plane framework may exhibit less comprehensive planning.

Furthermore, in the ERC-level model, the impact of commitment to the process on strategic plan formulation was positive, while its direct impact on commercialization productivity was negative. The conflicting coefficients can be explained by the properties of regression and mediation testing. When the indirect effects, via strategic plan formulation, were tested, only the two commitment variables were included as predictors. In this case, commitment to process emerged as having a positive effect on planning. However, when the direct effects on organizational outcomes were tested, all three planning variables were included in the model as predictors. As in any regression analysis, the results show the unique effects of each predictor (in this case, commitment to the tool, commitment to the process, and strategic plan formulation), while controlling for any overlapping effects among these predictors.

The negative direct effect of commitment to the process on commercialization productivity was the result of the unique aspect of commitment to the process, controlling for strategic plan formulation. In this case, commitment to the process likely reflects the operational aspects, or execution, of the strategic planning process. In other words, high commitment to the process may reflect an overemphasis on the mechanics of planning activities; this overemphasis may be detrimental to overall planning quality. However, strategic plan formulation, which reflects the extent and quality of planning, maintained a positive relationship with technology commercialization productivity, thereby exhibiting the positive benefits of strategic planning in an ERC.

A second finding warranting further discussion is also related to the benefits of strategic planning. Our results could be misconstrued as suggesting that a strategic planning process and the three-plane framework may not be beneficial to an ERC, because of the negative coefficients. However, that is not accurate. Instead, we emphasize the importance of a balanced approach to strategic planning. We believe that the comprehensiveness (i.e., formality and quality) of strategic plan formulation is the most important predictor of organizational effectiveness. Yet, commitment to the process of planning and commitment to the three-plane framework also are vital pieces of the strategic planning puzzle, when balanced properly.

On the other hand, overemphasis on either the activities of planning itself or on the mechanics of the three-plane framework may be detrimental to the ERC. Such overemphasis may occur when excessive time is spent on how to draw the three-plane framework or how to define levels of the framework in proper graphical terms. Overemphasis also may occur when the steps involved in the formal process of planning are followed to the letter, without flexibility for emerging ideas and creative planning exercises.

When a balanced level of commitment to the tool and the process is maintained, while keeping the larger purpose and vision of strategic planning in focus, the three-plane framework and a formal process of planning may be very powerful management tools for an ERC. We conclude that while strategic plan formulation is the most important predictor of positive organizational outcomes, it may be enhanced by balanced use of the three-plane framework and an appropriate planning process.

Appendix F contains a full technical report of the analyses used and the results as well as tables and figures summarizing the findings.

Recommendations and Best Practices

Recommendations to the ERC Leadership and Best Practices

ERC leaders. ERCs play a facilitative role in helping faculty members think about commercial applications of their research. Therefore, involvement in an ERC facilitates “role transitions” for faculty members from pure research to both research and technology commercialization. Some ERCs facilitate these transitions better than others and we uncovered a number of best practices involving faculty member role transitions.

For example, several universities have internal entrepreneurship mentoring. Often, volunteers are available in areas such as law, management, venture capital, and serial entrepreneurship. In many cases, the consultants are alumni of the ERC or the university; they can coach academics on how to participate in the commercialization of their research discoveries. These consultants also are a source of referrals for finding capital and managerial talent.

Other universities offer support to potential faculty entrepreneurs in advancing their technology in such a way that allows the faculty researcher to remain an academic researcher instead of trying to become a start-up’s CEO. We believe these models can be replicated in other places where the level of support is available from state, city, industry, and university sources. Examples of such university programs with which we are familiar are the Stanford Technology Ventures Program (http://stvp.stanford.edu), The MIT Entrepreneurship Center (http://mitsloan.mit.edu/faculty/c-entrepreneurship.php), and the Rice Alliance for Technology and Entrepreneurship (http://alliance.rice.edu/alliance/Default.asp).

Another best practice we observed involved creating a position titled "Industry Professorship" within the ERC. The industry professorship position has been designated as a non-tenure-track faculty member who brings the industry perspective inside the ERC. This person adds industry knowledge to the planning processes and to everyday execution of research. Overall, an Industry Professor can enhance the relevance of research to industry requirements.

Another best practice for maintaining the commercial relevance of ERC research involves communication mechanisms with the industry partners. Strong involvement from the industrial advisory board helps many ERCs become more successful. It also helps the ERC stay focused on real-world problems. This involvement provides an on-going critique of the broader "systems view" of commercialization and involves senior corporate scientists in the process. Further, it allows new perspectives and ideas to be raised as potential avenues of research in the ERC. Many ERCs have found that industry ideas contribute to plans about how new technology should be developed.

In addition to involvement from industry, an advisory board model that involves deans and university provosts has also proven successful. Their involvement in an advisory board can contribute to strategic planning effectiveness and funding support. Additionally, increased communication with counterparts at other ERCs, say, through advisory board membership, may be helpful in making decisions and identifying creative solutions to ERC challenges.

Many ERCs have had excellent experience with schemes to involve undergraduates in ERC research. ERCs that involve undergraduates in research have found it to be beneficial; the "naïve" questions raised by undergraduate students prove helpful in evaluating research problems and planning from different angles. Such involvement also gives undergraduate students experience in research project management.

Finally, we heard positive feedback about facilitated interactions among researchers within the ERC. Some faculty members suggested that social activities were helpful to bridging boundaries among independent researchers. Many ERCs and other types of research centers hold brown bag lunches or other types of semi-informal meetings meant to communicate current happenings and facilitate networking among ERC participants. This type of interaction helps increase collaboration and communication as well as intellectual exchange. Just as strategic planning can be an integrative force by encouraging knowledge sharing and communication, informal gatherings also increase serendipitous knowledge transfer and collaboration.

Industrial Liaison Officers (ILOs). The ILO is a central figure in creating an environment that fosters innovation and technology commercialization. Specifically, the more the ILO encourages technology transfer among researchers, the more successful the ERC tends to be. We saw many examples of best practices as we visited ERCs and talked with ILOs. For example, assisting researchers in working with the technology transfer office and/or with industry can be an important role for an ILO. Further, some ILOs are effective at marketing the technologies of the ERC to potential licensees. ILOs often facilitate "coffee-break" interactions with guest speakers and volunteer consultants who present their experiences on entrepreneurial topics. Overall, we found that ERC effectiveness was fostered when the ILO was a vital link between faculty, technology transfer professionals, and industry.

Recommendations to the ERC Program Leaders

In the earlier Key Qualitative Findings section, we mentioned a number of recommendations. Below we offer further suggestions, which are based on both our qualitative and quantitative results.

First, the general sentiment toward the Annual ERC Conference is extremely positive. The Conference provides an invaluable vehicle for information sharing. As speakers at the Conference, we were impressed with the value of NSF consultants, many of whom are typically former ERC leaders. The ERC Program leadership also may wish to consider providing other opportunities throughout the year for information sharing among ERCs (e.g., further opportunities for face-to-face or electronically-mediated communication). Even more frequent contact among current ERC leaders may help further diffuse best practices.

Second, we suggest implementation of an elaborated training program on strategic planning and three-plane framework for all new ERC directors and administrative directors. Training already takes place at the Conference but it would be prudent to add to existing training offerings. Training sessions should involve NSF representatives along with experienced directors and administrative directors. Because we found that knowledge of the three-plane framework was critical to both commitment to it and plan formulation, we believe that additional training may further enhance the effectiveness of ERCs.

Third, in training ERC leaders it would be advantageous to emphasize academically-oriented language in describing and explaining the three-plane framework. It must be explained in terms that academic researchers understand and embrace. Moreover, the intended uses and limitations of the three-plane framework should be reinforced. If it is understood and effectively implemented, the three-plane framework can be an even more valuable piece of the strategic planning puzzle.

References

Absher, M., Bryers, J., Costerton, W., Fletcher, S., Johnson, K., Joyce, D., et al. (2004). *ERC Best Practices Manual*

Aranya, N., Pollock, J., & Amernic, J. (1981). An examination of professional commitment in public accounting. *Accounting, Organizations, and Society, 6*(4), 271-280.

Banner, D. K., & Gagné, T. E. (1995). *Designing Effective Organizations: Traditional & Transformational Views*. Thousand Oaks, CA: Sage Publications.

Baron, R. M., & Kenny, D. A. (1986). The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*(6), 1173-1182.

Bliese, P. D. (2000). Within-group agreement, non-independence, and reliability: Implications for data aggregation and analysis. In K. J. Klein & S. W. Kozlowski (Eds.), *Multilevel Theory, Research, and Methods in Organizations* (1st ed.). San Francisco: Jossey-Bass.

Bline, D. M., Duchon, D., & Meixner, W. F. (1991). The measurement of organizational and professional commitment: An examination of the psychometric properties of two commonly used instruments. *Behavioral Research in Accounting, 3*, 1-12.

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*. Mahwah, N.J.: Lawrence Erlbaum Associates, Inc.

Currall, S. C., & Judge, T. A. (1995). Measuring trust between organizational boundary role persons. *Organizational Behavior and Human Decisions Processes, 64*(2), 151-170.

Currall, S. C., Hammer, T. H., Baggett, L. S., & Doniger, G. M. (1999). Combining qualitative and quantitative methodologies to study group processes: An illustrative study of a corporate board of directors. *Organizational Research Methods, 2*(1), 5-36.

Di Gregorio, D., & Shane, S. (2003). Why do some universities generate more start-ups than others? *Research Policy, 32*, 209-227.

Edelman, L. B. (1992). Legal ambiguity and symbolic structures: Organizational mediation of civil rights law. *American Journal of Sociology, 97*, 1531-1576.

Gist, M. E., Locke, E. A., & Taylor, M. S. (1987). Organizational behavior: Group structure, process and effectiveness. *Journal of Management, 13*(2), 237-257.

Hoffman, D. A. (1997). An overview of the logic and rationale of hierarchical linear models. *Journal of Management, 23*(6), 723-744.

Kallman, E. A., & Shapiro, H. J. (1978). The motor freight industry: A case against planning. *Long Range Planning, 11*, 81-86.

Ketokivi, M., & Castaner, X. (2004). Strategic planning as an integrative device. *Administrative Science Quarterly, 49*, 337-365.

Manz, C. C., Keating, D. E., & Donnellon, A. (1990). Preparing for an organizational change to employee self-management: The management transition. *Organizational Dynamics, 19*(2), 15-26.

McCall, M. W., & Bobko, P. (1990). Research methods in the service of discovery. In M. D. Dunnette & L. M. Hough (Eds.), *Handbook of Industrial and Organizational Psychology* (2nd ed., pp. 381-418). Palo Alto, CA: Consulting Psychologists Press.

Meyer, J. P., Stanley, D. J., Herscovitch, L., & Topolnytsky, L. (2002). Affective, continuance, and normative commitment to the organization: A meta-analysis of antecedents, correlates, and consequences. *Journal of Vocational Behavior, 61*, 20-52.

Meyer, J. W., & Rowan, B. (1977). Institutionalized organizations: Formal structure as a myth and ceremony. *American Journal of Sociology, 83*, 340-363.

Meyer, J. W., & Scott, W. R. (1983). *Organizational environments: Ritual and rationality.* Beverly Hills, CA: Sage Publications.

Miller, C. C., & Cardinal, L. B. (1994). Strategic planning and firm performance: A synthesis of more than two decades of research. *Academy of Management Journal, 37*(6), 1649-1665.

Mintzberg, H. (1994). *The Rise and Fall of Strategic Planning*. New York, NY: The Free Press.

National Science Foundation. (2005). *Engineering Research Centers: Creating Leading Technologies, Educating Technology Leaders*. Washington: National Science Foundation.

Ostroff, C., & Schmitt, N. (1993). Configurations of organizational effectiveness and efficiency. *Academy of Management Journal, 36*(6), 1345-1361.

Porter, L. W., Steers, R. M., Mowday, R. T., & Boulian, P. V. (1974). Organizational commitment, job satisfaction, and turnover among psychiatric technicians. *Journal of Applied Psychology, 59*, 603-609.

Qu, A. (1997). *Comparison of PROC MIXED in SAS and HLM for hierarchical linear modeling*. Unpublished manuscript.

Ramanujam, V., Venkatraman, N., & Camillus, J. C. (1986). Multi-objective assessment of effectiveness of strategic planning: A discriminant analysis approach. *Academy of Management Journal, 29*, 347-372.

Reid, D. M. (1989). Operationalizing strategic planning. *Strategic Management Journal, 10*, 553-567.

Rousseau, D. M. (1985). Issues of level in organizational research: Multilevel and cross-level perspectives. *Research in Organizational Behavior, 7*, 1-37.

Shane, S., & Stuart, T. E. (2002). Organizational endowments and the performance of university start-ups. *Management Science, 48*, 154-170.

Sine, W. D., Shane, S., & Di Gregorio, D. (2003). The halo effect and technology licensing: The influence of institutional prestige on the licensing of university inventions. *Management Science, 49*(4), 478-496.

Shrout, P. E., & Bolger, N. (2002). Mediation in experimental and non-experimental studies: New procedures and recommendations. *Psychological Methods, 7*(4), 422-445.

Smilor, R. W., Dietrich, G. B., & Gibson, D. V. (1993). The entrepreneurial university: The role of higher education in the United States in technology commercialization and economic development. *International Social Science Journal, 45*(1), 1-11.

Smith, K. G., Locke, E. A., & Barry, D. (1990). Goal setting, planning, and organizational performance: An experimental simulation. *Organizational Behavior and Human Decisions Processes, 46*, 118-134.

Steenhuis, H. J., & Gray, D. O. (2005). Strategic decision-making in publicly funded innovative organizations: An exploratory study. *International Journal of Technology Transfer and Commercialisation, 4*(2), 127-147.

Stuart, T. E. (2000). Interorganizational alliances and the performance of firms: A study of growth and innovation rates in a high-technology industry. *Strategic Management Journal, 21*, 791-811.

Tabachnick, B. G., & Fidell, L. S. (2001). *Using Multivariate Statistics* (4th ed.). Boston, MA: Allyn and Bacon.

Tetrick, L. E., & Farkas, A. J. (1988). A longitudinal examination of the dimensionality and stability of the Organizational Commitment Questionnaire (OCQ). *Educational and Psychology Measurement, 48*, 723-735.

Tuma, N. B., & Grimes, A. J. (1981). A comparison of models of role orientations of professionals in a research-oriented university. *Administrative Science Quarterly, 26*, 187-206.

Veliyath, R., & Shortell, S. M. (1993). Strategic orientation, strategic planning system, characteristics, and performance. *Journal of Management Studies, 30*(3), 359-381.

Wang, X., & Armstrong, A. (2004). An empirical study of PM professionals' commitment to their profession and employing organizations. *International Journal of Project Management, 22*, 377-386.

Wilkinson, G. S. (1974). Social psychological dimensions of resistance to psychiatric innovations. *Psychological Reports, 34*(3, Pt 2), 1083-1085.

List of Appendices

Appendix A: Informed Consent Letter

For Interviews

Dear Sir or Madam:

We invite you to participate in a research project funded by the National Science Foundation, Division of Engineering Education and Centers. Lynn Preston, Deputy Division Director and Leader of the Engineering Research Centers Program, and Dr. Linda Parker, Engineering Program Evaluation Director, have approved the grant supporting our research. As part of the cooperation agreement between your Engineering Research Center (ERC) and the National Science Foundation, you are expected to participate in this research project. Researchers from Rice University, Columbia University, and the University of Houston are conducting the research: Professor Steve Currall (PI), Professor Jing Zhou, Professor Toby Stuart, and Sara Jansen.

The study will examine how ERCs engage in strategic planning and how ERCs organize themselves for maximum effectiveness. By learning what works best and sharing what is learned across ERCs, the study will enhance the impact of the ERC program as a whole. This project complements information in the existing *ERC Best Practices Manual* (Absher et al., 2004) by focusing on how strategic planning is conducted in ERCs as well as the related topics of management of engineering and scientific advances developed by ERC researchers and the creativity and innovation of ERC engineers and scientists. The project concludes in mid-2006.

We are inviting you, and about 30 other individuals from the 22 ERCs from around the country, to participate in the interview portion of the project. Only about one hour of your time will be required for the interviews. During 2005, all faculty, administrators, post-docs, and graduate students at each of the 20 ERCs will be asked to respond to a brief survey about the project. At no time during this project will individuals be identified. The data we receive from interviews and surveys will be aggregated and identifying information detached from individual responses to assure full confidentiality. In group interviews, all participants will be encouraged to maintain the confidentiality of the input provided in the session.

At the conclusion of the project, we may publish our aggregate results in professional and/or scientific journals and other literature. Our findings also may be used for educational purposes or for academic presentations. No harm can come to you because of the information you provide; our results will only be communicated in an aggregated form. Full confidentiality of your input will be maintained at all times. However, if you do not want your input used for these purposes, you have the right to refuse consent. By responding to the email containing this letter, you will confirm that you allow us to use the data you provide for the above purposes. This project has been reviewed by the University of Houston and Rice University's Committee for the Protection of Human Subjects. You may contact the UH IRB at (713) 743-9204 or the Rice IRB at (713) 348-6203 if you have any questions regarding your rights. We appreciate your participation and welcome any questions you may have.

Sincerely,

Steven C. Currall, Ph.D.
William and Stephanie Sick Professor of Entrepreneurship
Associate Professor of Management, Psychology, and Statistics
Rice University

Sara K. Jansen
Doctoral Candidate
Industrial/Organizational Psychology
University of Houston
skjansen@central.uh.edu

For Surveys

Dear Sir or Madam:

We invite you to participate in a research project funded by the National Science Foundation, Division of Engineering Education and Centers. Lynn Preston, Deputy Division Director and Leader of the Engineering Research Centers Program, and Dr. Linda Parker, Engineering Program Evaluation Director, have approved the grant supporting our research. As part of the cooperation agreement between your Engineering Research Center (ERC) and the National Science Foundation, you are asked to participate in this research project. Researchers from Rice University (Professor Steve Currall – PI), Harvard Business School (Professor Toby Stuart), and the University of Houston (doctoral students Sara Jansen and Emily Hunter) are conducting the research.

The study will examine how ERCs engage in strategic planning and how ERCs organize themselves for maximum effectiveness. By learning what works best and sharing what is learned across ERCs, the study will enhance the impact of the ERC program as a whole. This project complements information in the existing *ERC Best Practices Manual* by focusing on how strategic planning is conducted in ERCs as well as the related topics of management of engineering and scientific advances developed by ERC researchers and the creativity and innovation of ERC engineers and scientists. The project concludes in mid-2006.

We are inviting you, along with other individuals from the 22 ERCs around the country, to participate in the survey portion of the project. During 2005, representatives from each of the 20 ERCs participated in in-depth interviews, which aided the researchers in creating a brief and relevant survey. Only about 30 minutes of your time will be required to complete this survey.
When you responded to the email invitation to participate in this survey (by clicking on the survey link), a unique ID was reported to this online survey program. This unique ID code and all survey responses are only available to the researchers, and at no time during this project will you, as an individual, be identified. The data we receive from interviews and surveys will be aggregated and we assure full confidentiality of your responses. Therefore, please answer all questions honestly. No individual data or information will be shared with NSF. Our study has no bearing whatsoever on NSF funding decisions.

At the conclusion of the project, we may publish our aggregate results in professional and/or scientific journals and other literature. Our findings also may be used for educational purposes, student dissertations, or for academic presentations. No harm can come to you because of the information you provide; our results will only be communicated in an aggregated form. Full confidentiality of your input will be maintained at all times.

However, if you do not want your input used for these purposes, you have the right to refuse consent. By clicking on the “I Agree” button below, you will confirm that you allow us to use the data you provide for the above purposes. This project has been reviewed by the University of Houston and Rice University’s Committee for the Protection of Human Subjects. You may contact the UH IRB at (713) 743-9204 or the Rice IRB at (713) 348-6202 if you have any questions regarding your rights. We appreciate your participation and welcome any questions you may have.

Sincerely,

Steven C. Currall, Ph.D.
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Appendix B: Interview Items

General Effectiveness Questions

1. Is there discrepancy between your opinion of the definition of good performance, the ERC's opinion, and/or the NSF's definition?
2. What resources, policies, or changes could increase your ERC's performance/productivity/effectiveness?
3. Is there a need to generate multiple annual reports because of differing requirements put forth by the NSF and your partners?
   How many annual reports do you produce?
4. What percentage of the ERC leadership's time is spent on long-term decisions, pulling all of the facets of the ERC together to make the overall impact? This includes defining goals, pathways to goals, and allocating resources needed to achieve goals. (Strategic)
   a. What proportion of the ERC leadership's time is spent on long-term, strategic activities versus short-term, day-to-day tactical activities?
5. What percentage of the ERC leadership's time is spent on day-to-day, short term decisions, including addressing issues as they arise, shifting resources as needs arise, and administrative duties? (Tactical)
6. Do you feel confident that you and the other leaders of the center are on the same page on these concepts?
   a. Concepts:
      i. Core Guiding Beliefs (unique, core of day-to-day operations, mission statement)
      ii. Mandatory stakeholder commitments
      iii. Long-term purpose and ambition (vision for future, strategic, aspirational goals)
      iv. Strategically relevant and unique assets of your ERC (difficult to duplicate, central to value proposition)

Strategic Planning Process (Formulation) Questions

7. What type of strategic planning processes and tools do you use to plan your research activities and resources, other than the three-plane?
8. How knowledgeable and comfortable do you feel with strategic planning in general?
9. How knowledgeable and comfortable do you feel with the three-plane framework?
10. Who participates in the strategic planning process?
11. What challenges do you need to address in order to involve multiple participating universities in the strategic planning process?
12. In your opinion, do most participants take personal responsibility for the outcome of the strategic planning process?
13. What external resources are used? (i.e., books, consultants, industry, IAB, Lynn/Linda/NSF, other universities)
14. How much total time is spent on the three-plane strategic planning process?
15. How much of this time do you consider useful to you or your ERC?
16. Any feedback loops in the process?
    a. Is feedback solicited at any point in the strategic planning process?
17. If yes, what stages are used as milestones for soliciting feedback in the feedback-planning cycle?
18. Have you made tweaks to the existing three-plane?
19. Have you used the three-plane for other non-ERC proposals or planning?
20. How well does the three-plane allow for a balance of creativity and control?
21. How adaptable and flexible is the three-plane framework?
22. Is the three-plane framework or the generated plan of assistance in decision-making in daily operations at your ERC?

23. Does the three-plane cover all the areas it needs to cover in the realm of strategic planning for your ERC?
24. Do you experience resistance from any participant in ERC strategic planning process?
    a. If so, how do you deal with it? How do you work around it? How do you grow from it, allowing you to make the process more productive?

Implementation of Strategic Plan Questions

25. How does the three-plane framework affect resource allocation in your ERC?
26. How is the annual strategic plan, or each milestone, communicated to rest of ERC and all stakeholders in particular?
27. In what other ways is the final annual strategic plan used?
28. How valuable do you view the final product of this planning?
29. How does the final product link to the effectiveness indicators, and impact your ERC?
30. How often, if ever, is the annual plan revisited, referred to in daily operations, or refined over the year?
31. How is compliance with your strategic plan monitored by the ERC leadership?
32. How integrated is your strategic plan into your day-to-day operations?
33. What do you think about the three-plane as an organizing function in planning for the center, in general?

ERC Team Questions

34. How closely do the members of each research thrust work?
35. What level of communication must go on among the thrusts? Among other teams in your ERC?
    a. How well do thrusts accomplish the needed level of communication?

Industry Partnering Questions

36. Do you find varying degrees of complexity between industry partnering agreements?
37. Are industry partners satisfied with pace and direction of work done at the center?
    a. How much access do they have?
    b. How do they feel about technology transfer process?
38. Do industry partners have an active voice in the questions that are researched at the center?
39. Have industry partners formed active consulting arrangements with affiliated faculty?
40. Do industry partners attend seminars/outreach programs?
    a. Do they benefit from these and other ways of informal knowledge sharing?
    b. Is there access to knowledge exclusively through formal contracting mechanisms?
41. How strong/close is the relationship between you and your industry partners?
42. How strong/close is the relationship between you and your university members of the ERC?
43. How does the strength of your relationship affect those entities' level of involvement in the ERC in general and specifically in the strategic planning process?
    a. To what degree do you involve industry in the process?
    b. To what degree do they want to be involved in the process?
44. What are the main reasons that industry partners want to be affiliated with your ERC?
45. Do you see an air of competitive cooperation, where competing companies can communicate without lawyers and share industry knowledge?
46. Are you willing to share any of your contacts in industry so we can further ask them about these partnerships?
47. Are you willing to share data at each stage of the technology transfer process (e.g., allocation of dollars to projects, invention disclosed, patent filed, license crafted)?
48. In your opinion, is the ILO changing or evolving? For example, are you now taking on more direct responsibilities in negotiating agreements, including IP?

Appendix C: Survey Items

Instructions

The following questions ask you about your affiliations and perceptions of your ERC. When we ask you to answer questions referring to "my ERC" we are asking about the ERC with which you have your main affiliation.

Informed Consent

1. Do you agree or disagree to continue and let us use your data? Yes No

Demographics

1. I currently have an active formal affiliation with my ERC. Yes No
2. I am an alumnus of my ERC but I do not currently have an active formal affiliation with the ERC. Yes No
3. Please indicate your title within the university (i.e., the university where you have your primary employment). Please choose all that apply:
    a. Assistant Professor
    b. Associate Professor
    c. Full Professor
    d. Endowed or Named Professorship
    e. Emeritus Professor
    f. Adjunct Professor
    g. Visiting Professor
    h. Lecturer
    i. Department Chair
    j. Administrative Staff
    k. Research Scientist
    l. Research Support Personnel
    m. Postdoctoral Researcher
    n. Graduate Student
    o. Undergraduate Student
    p. Other (Please list)
4. Are you eligible to supervise students? Yes No Not Applicable/I'm not a faculty member
5. Are you eligible to attend faculty meetings? Yes No Not Applicable/I'm not a faculty member
6. Please indicate the ERC with which you are affiliated (if more than one, please choose the one which is your primary, or takes the majority of your time): <Choices listed>
    a. *Note: Please respond to the rest of the items in this survey with regard to the ERC you chose here.*
7. Are you are employed by the lead university of your ERC? Yes No

8. My position within my ERC (Please choose all that apply):
    a. Director
    b. Deputy, Assistant, or Associate Director
    c. Administrative Director/Manager
    d. Industrial Liaison Officer
    e. Educational/Outreach Director
    f. Testbed Leader
    g. Thrust Leader
    h. Project Leader
    i. Other leadership role (Please list)
    j. General ERC Faculty Member – no formal administrative or leadership role in ERC
    k. Support Staff (Please list title)
    l. Postdoctoral Researcher
    m. Graduate Student
    n. Undergraduate Student
    o. Other (Please list)
9. Were you a member of the ERC when it received its initial funding from NSF? Yes No
    a. If no, in what calendar year did you join the ERC (e.g., 1997)?
10. I have received research or educational support funds from the ERC for ___ year(s).
11. Please indicate your gender: M F

Please indicate the degree to which you agree with each statement.
12. I sought out affiliation with my ERC before I joined it.
13. Before I joined my ERC, representatives from the ERC sought me out to join the center.

Instructions

For the remainder of this survey, except where specific instructions are listed, please mark the answer corresponding to the extent to which you agree or disagree with each statement. When we ask questions about "my ERC" please answer with regard to the ERC you marked as your primary ERC affiliation, in Question 6.

Awareness

1. I was involved in creating the proposal to NSF, before my ERC was funded.
2. I am involved in the strategic planning process that occurs in my ERC.
3. I am aware of my ERC's strategic plan.
4. I am aware of the term "three-plane framework."
5. I am aware of the intended purpose of the three-plane framework.
6. I am aware of my ERC's industrial partnering practices.

Commercialization Support

1. Commercialization of ERC research is encouraged in my ERC.
2. Commercialization of ERC research is encouraged at my university (i.e., where I hold my main employment).
3. Commercialization of ERC research is encouraged in my home academic department.
4. The Office of Technology Transfer (or Licensing) at my university is easy to work with in the process of commercialization.
5. The Office of Technology Transfer (or Licensing) at my university is effective in carrying out its responsibilities in the process of commercialization.
6. The Industrial Liaison Officer (ILO) in my ERC assists faculty with commercialization processes.

7. The Industrial Liaison Officer (ILO) in my ERC successfully encourages faculty members to become involved in the process of commercialization.
8. Management talent is available to assist researchers in my ERC in launching start-up companies.
9. Incubator services are available to assist researchers in my ERC in launching start-up companies.
10. Because I participate in my ERC, I have (please check all that apply)
    a. initiated a new line of research.
    b. increased my technology transfer activity.
    c. begun a project with industry.
    d. begun a project with colleagues in other disciplines.
    e. presented my research findings to industry.
    f. accepted input from industry.
    g. accepted input from colleagues in other disciplines.
    h. increased opportunities for consulting to industry.
    i. improved my promotion and/or tenure prospects.
    j. Other (please list)

Perceptions of ERC Impact

Definition
Industry affiliate companies are those with which your ERC has a formal agreement.

My ERC's Impact on my Individual Work in Relation to Commercialization
1. Since joining my ERC, my attitude regarding research has shifted to be more mindful of commercialization activities.
2. Because of my involvement with my ERC, I have increased opportunities for involvement in commercialization activities.
3. Since joining my ERC, I have had increased contact with people representing industry.
4. Since joining my ERC, my attitude regarding collaboration with industry has become increasingly positive.
5. Since joining my ERC, the content of my research has become more oriented toward commercialization.
6. Since joining my ERC, my research has become more applied in nature.
7. My reasons for participating in my ERC include (please check all that apply):
    a. To earn prestige
    b. To obtain additional funding
    c. To interact with colleagues
    d. To work on a specific research project
    e. To find multidisciplinary collaboration opportunities
    f. To interact with industry affiliate companies
    g. To ensure my research has an impact on society
    h. To gain access to infrastructure provided by the ERC
    i. To gain access to students
    j. Other (please list)

My ERC's Overall Impact in Relation to Commercialization
1. My ERC has shifted the culture among researchers to be more mindful of commercialization activities.
2. Within my ERC, there are good examples of academic researchers who have succeeded in commercialization activities.
3. My ERC helps develop a common language among researchers from various disciplines in order to foster collaboration.

4. One of the barriers to collaboration between my ERC and industry affiliate companies is a difference in timeframe for commercialization. [REVERSE]
5. My ERC is successful at enhancing the impact of my research on society.
6. One advantage of the ERC is that it emphasizes a longer time horizon for research compared to grants to individual faculty members.
7. My ERC provides crucial infrastructure for collaboration with researchers with whom I would not normally collaborate.
8. My ERC has been successful at creating start-up companies.

My ERC & Industry Partnering
1. My ERC provides crucial infrastructure for work with industry affiliate companies.
2. My ERC creates barriers to my direct interactions with industry affiliate companies. [*reverse*]
3. My ERC helps develop a common language with industry affiliate companies, which helps foster commercialization.
4. Our industry affiliate companies are interested in start-up companies founded by my ERC, which they can later acquire.
5. My ERC's industry affiliate companies influence the identification of research projects by researchers in my ERC.
6. My ERC's industry affiliate companies vary in the type of research in which they are interested (i.e., basic research, enabling technologies, or engineered systems).

Leveraged Funding Opportunities
1. I have been able to leverage research in the ERC to obtain other non-ERC funding for my work.
2. I have observed others in my ERC bring in funding for non-ERC research as a result of research being done in the ERC.

Institutional Characteristics

Organizational Structure
1. The director and other leaders of my ERC protect the faculty from most bureaucratic processes.
2. The organizational chart of administrative leadership in my ERC consists of many levels.
3. The organizational chart of administrative leadership in my ERC is well-defined.

Attitudinal Characteristics

Organizational Commitment to ERC (Porter et al., 1974)

1. I am willing to put in a great deal of effort beyond that normally expected in order to help this ERC be successful.
2. I talk up this ERC to my friends as a great organization to be associated with.
3. I would accept almost any type of job assignment in order to keep working with this ERC.
4. I find that my values and the ERC's are very similar.
5. I am proud to tell others that I am part of this ERC.
6. This ERC really inspires the very best in me in the way of job performance.
7. I am extremely glad that I chose this ERC to work with over others I was considering at the time.
8. I really care about the fate of this ERC.
9. For me, this ERC is the best of all possible organizations with which to work.

Professional Commitment (Wang & Armstrong, 2004)
Please mark the answer most appropriate, on a scale from Very Unimportant to Very Important.

1. Build my professional reputation in my field.
2. Belong to the professional community of others in my field.
3. Improve my knowledge in my field.
4. Have adequate career prospects within my chosen profession.
5. Keep contact with others in my profession.
6. Earn respect in the eyes of colleagues in my field outside my employing organization.
7. Have an adequate level of salary relative to colleagues in my field outside my employing organization.

Collaboration Activities

Intellectual Network of Collaboration
1 – 7**.** Please think back over the entire course of the time you have been affiliated with your ERC. In the spaces provided below, please list the eight individuals whose input you have valued most in your research activities during that time. For each colleague, please indicate the degree to which you value the input of that person in regards to the content and direction of your own research.

Colleague First/Last Name	Do not value	Slightly value	Moderately value	Value a great deal	Value extremely
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5

Intra-ERC Porosity
1. Collaboration (e.g., research, publications) occurs among the projects within each thrust.
2. Collaboration (e.g., research, publications) occurs among thrusts.
3. Collaboration (e.g., research, publications) occurs among project teams that operate on different levels of the three-plane framework.
4. My involvement with students and/or post-docs increases my collaboration (e.g., research, publications) with people in other thrusts.
5. My ERC has a formal committee or team devoted to promoting collaboration across the thrusts.
6. The thrusts are structured in such a way that requires collaboration across levels of the three-plane framework.
7. The project teams are structured in such a way that requires collaboration across levels of the three-plane framework.

8. Within the thrusts in my ERC, multidisciplinary research is carried out.
9. The structure of thrusts has evolved over time in order to remain focused on multidisciplinary research.

Extra-ERC Porosity

1. Communication occurs among faculty in my ERC and industrial affiliate companies.
2. Collaboration (e.g., research, publications) occurs among faculty in my ERC and industrial affiliate companies.

Strategic Planning Attitudes

Acceptance of the Three-Plane Framework

1. People in my ERC have a positive opinion of the three-plane framework for use in strategic planning.
2. I have a positive opinion of the three-plane framework for use in strategic planning.

Strategic Plan Formulation

1. My ERC holds strategic planning sessions throughout the year.
2. My ERC has a defined mission and the strategic plan reflects that mission.
3. My ERC has sufficient involvement in the strategic planning process from all persons affiliated with it. (Veliyath & Shortell, 1993) [*edited*]
4. My ERC articulates its goals and strategic plans to all persons affiliated with the ERC.
5. My ERC revisits the process of strategic planning yearly.
6. Long range plans (for more than one year ahead) for my ERC are prepared (Kallman & Shapiro, 1978). [*edited*]
7. Strengths and weaknesses of the ERC are systematically analyzed and considered when developing plans (Kallman & Shapiro, 1978). [edited]
8. Industry support trends are analyzed and forecasted as input to the planning process. [edited]
9. The market trends applicable to our ERC research are analyzed and forecasted as input to the planning process.
10. Alternate courses of action for each goal are thoroughly evaluated (Kallman & Shapiro, 1978).
11. My ERC's strategic planning process would benefit from more involvement of all members and participants in the ERC. [*reverse*]

Commitment to Strategic Planning Process

1. My ERC sees the need to do strategic planning (Smith et al., 1990).
2. My ERC depends on a formal process to develop our strategic plan.
3. My ERC is enthusiastic about strategic planning (Smith et al., 1990). [*edited*]
4. My ERC places a high priority on strategic planning sessions.
5. The director of my ERC expends significant effort to communicate the value of strategic planning to everyone involved with my ERC.

Commitment to Use of the Three-Plane Framework

1. My ERC depends on the three-plane framework to develop our strategic plan.
2. My ERC has found the three-plane framework sufficiently useful so that it is used in non-ERC planning projects.
3. My ERC has customized the three-plane framework in order to tailor it to our ERC's unique needs and/or characteristics.

4. The director of my ERC expends significant effort to communicate the value of the three-plane framework to everyone involved with my ERC.

Perceived Value of Three-Plane Framework

1. The three-plane framework provides an effective way to organize our thoughts in developing our strategic plan.
2. The third plane ("engineered systems" plane) is an effective mechanism to interface with industry.
3. The three-plane framework is effective at focusing my ERC on its overarching goals.
4. The three-plane framework helps my ERC avoid distracting research activities that are not well-aligned with its mission.
5. The three-plane framework is an appropriate tool for the field in which my ERC does research.

Knowledge of Tool

1. I have been trained on the use of the three-plane framework in strategic planning.
2. I understand where my research projects fit into the three-plane framework.
3. I am sufficiently familiar with the three-plane framework that I could participate in using it to develop a strategic plan for my ERC.

Capability of Three-plane to Facilitate Regular Balancing and Rebalancing of Resources across Thrusts and Projects

1. The three-plane framework helps my ERC's leaders establish priorities in allocating resources.
2. The three-plane framework helps my ERC's leaders effectively re-allocate resources as needed.
3. The three-plane framework helps my ERC's leaders communicate resource allocation decisions.

Appendix D: Examples of Alterations and Supplements to Three-Plane Framework

Figure D1. **Example Supplementary Management Tool**
As a supplement to the three-plane chart, this strategic timeline helps clarify the lifecycle of planned research programs and technologies.

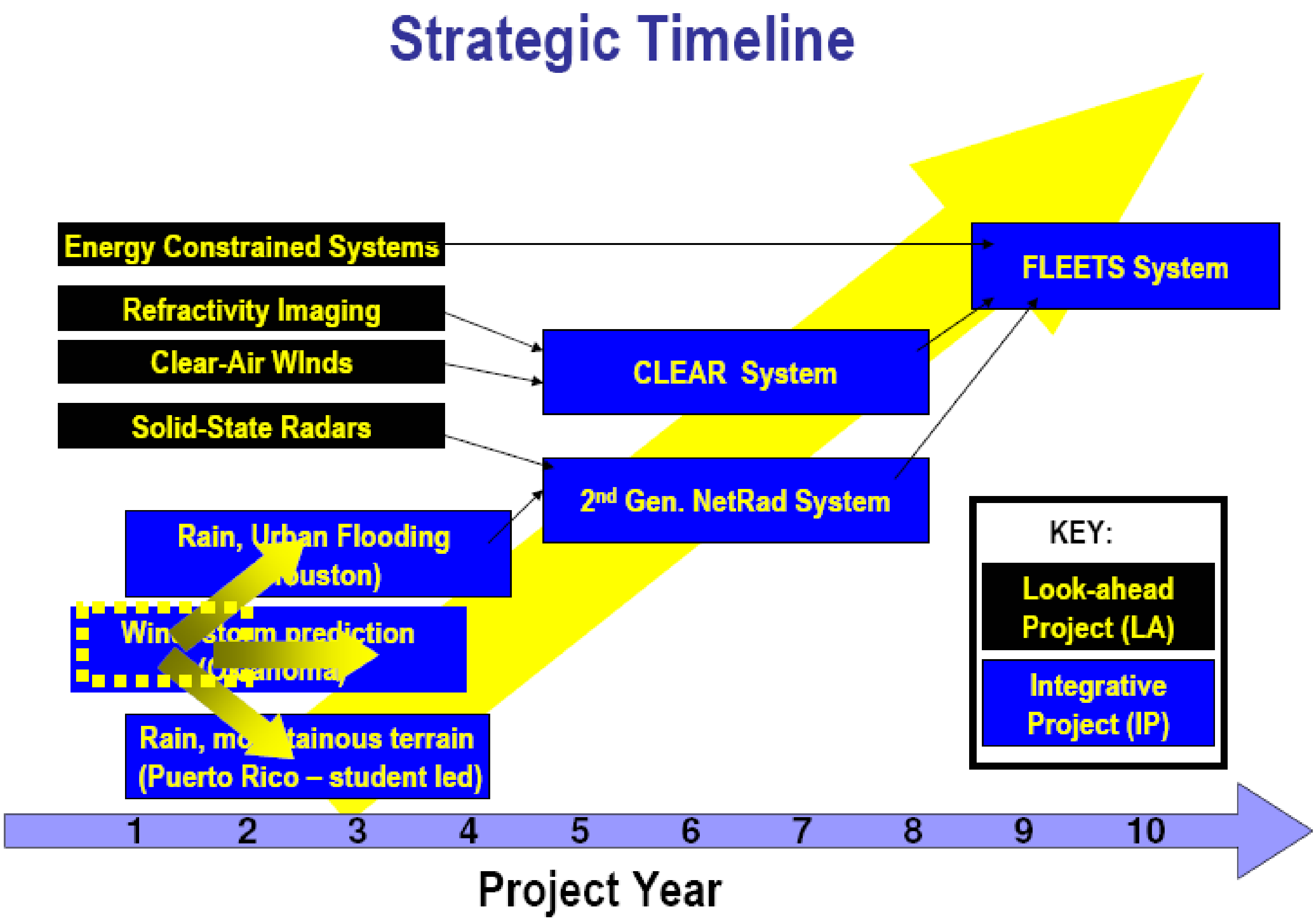


***Figure D2.* Example Three-Plane Framework**

This three-plane chart is helpful in presenting the collaborations and dependencies among project teams in the ERC. Explicitly depicting the links among the three levels and among projects within the same level is useful in reporting the ERC's plan for research.

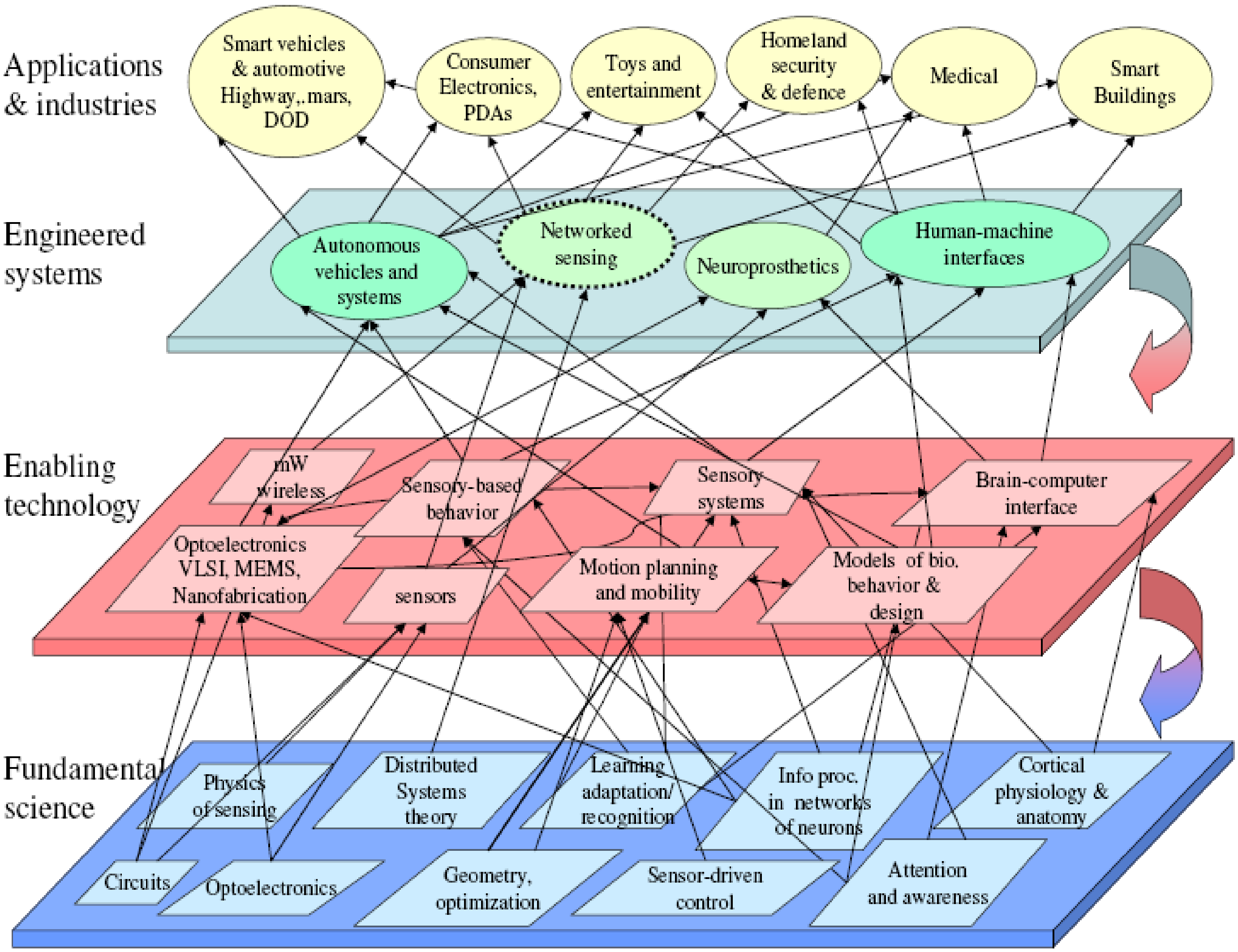


***Figure D3.* Example Thrust-specific Three-plane Supplement**
As a supplement to the three-plane framework, this chart provides an integrated timeline and three-plane framework specific to each thrust. When each thrust is aware of its specific objectives, especially in terms of timeline, the strategic plan is better implemented throughout the ERC.

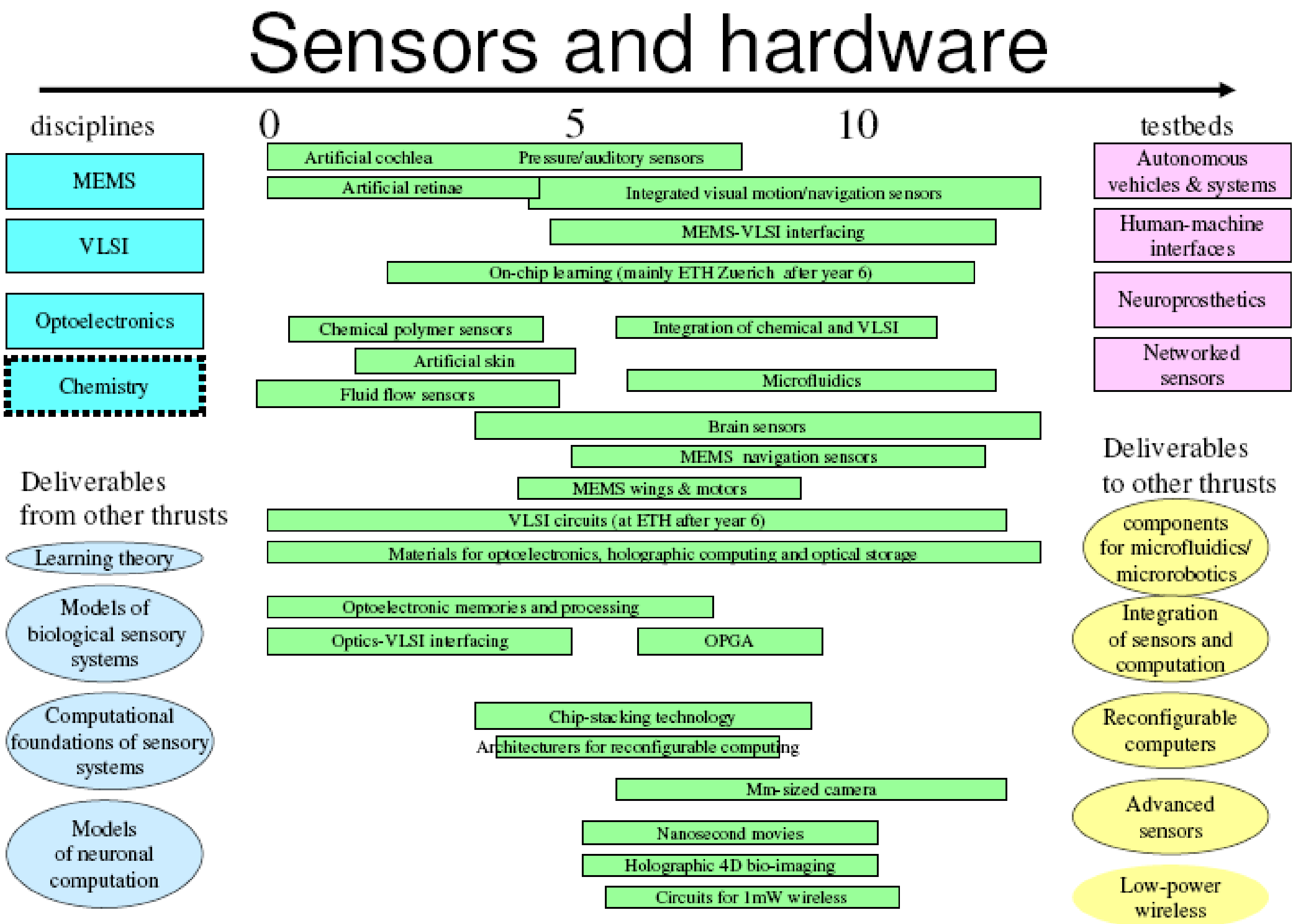


***Figure D4.* Example of Alternative Communication Tool**
As a supplement to the three-plane framework, this diagram helps communicate the ERC's objectives in an alternative manner. By including the role of constituencies and the stages at which the technologies are used, the ERC can communicate to potential industry partners and researchers effectively.

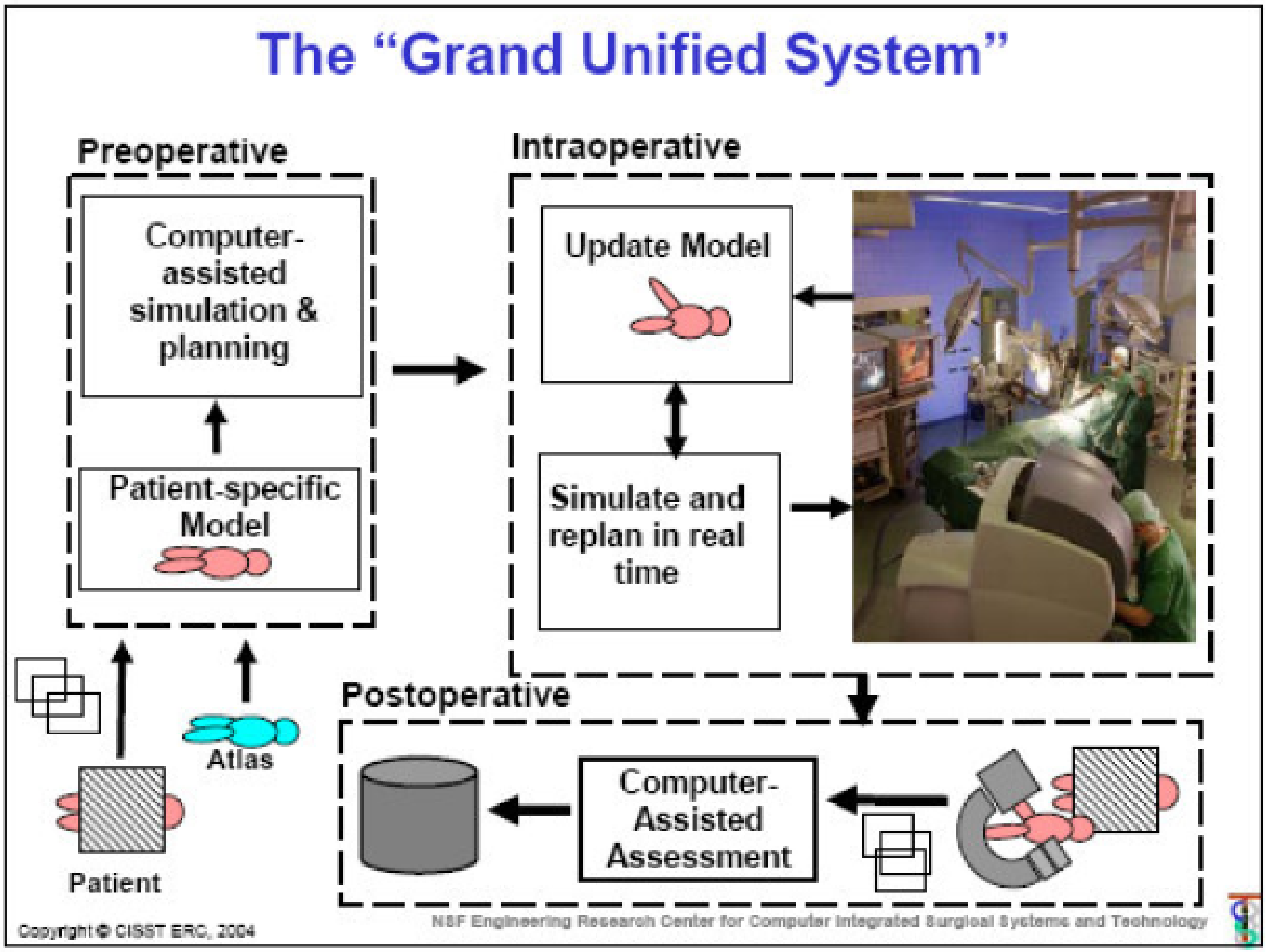
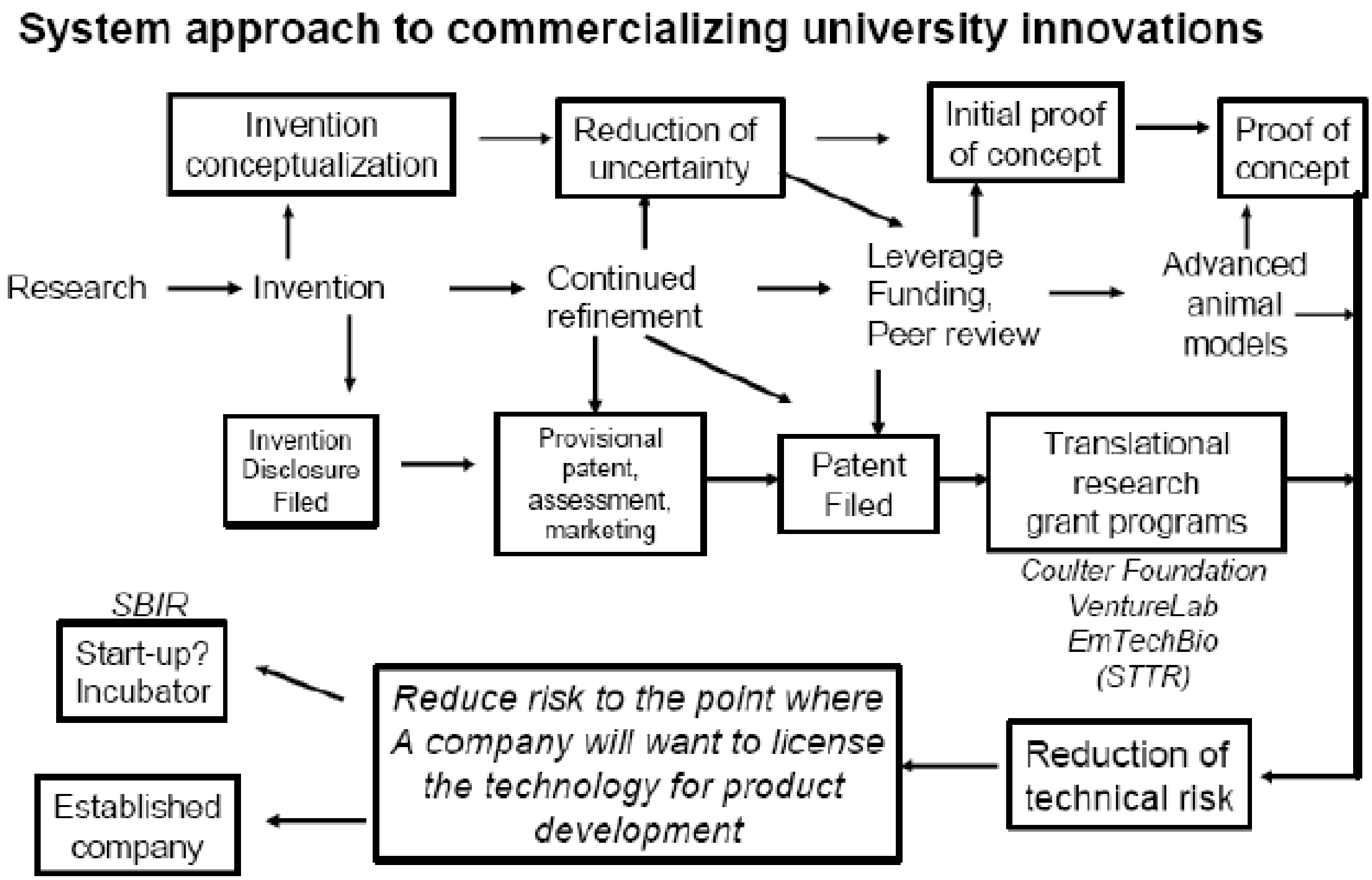


Figure D5. **Applying the Three-Plane to Technology Commercialization Pipeline**
This diagram helps the ILO communicate the process of commercialization in the ERC. It uses a system approach, like the three-plane framework supports, in order to look at the big picture and effectively communicate to all constituents.



Appendix E: Technical Details of Methodology

Design

A cross-sectional design was used. Participants worked in existing workgroups and research organizations in a field setting. Qualitative interviews were carried out from January through September 2005. These functioned as fact-finding, hypothesis-generating interviews in order to develop a survey instrument. They also served to gather best practices from various ERCs. In addition to the qualitative interviews, a survey was administered in November through December 2005. Finally, archival data was used throughout the analyses for the quantitative performance measures. This data existed in the form of annual reports from 2001 to 2005 for each of the 22 ERCs.

The present study sought to maximize methodological rigor and continue to build on the practice of combining qualitative and quantitative data (Currall, Hammer, Baggett & Doniger, 1999). Methodological rigor is maximized by multi-source, multi-method data collection, combining qualitative and quantitative data collection into a single field-based, organizational-level study. Combining these two types of data adds an extra level of contextual detail and interpretability to the results of the study (Currall et al., 1999). Especially in conducting field research in real organizations, interactions and idiosyncrasies of a phenomenon under study cannot be understood from quantitative data collection alone. Because both types of data possess disadvantages as well as advantages, it is most appropriate to find a balance in a combination of qualitative and quantitative data collection (McCall & Bobko, 1990).

Measurement

A survey comprising of approximately 120 questions was administered via an online survey tool. For the majority of items, a 7-point Likert scale was used with verbal anchors ranging from "Strongly Agree" to "Strongly Disagree." When possible, existing, pre-validated measures were used. Appendix C lists the survey items.

Organizational outcomes. The best way to measure organizational effectiveness is through use of multiple measures (Banner & Gagné, 1995; Ostroff & Schmitt, 1993). A variety of performance indicators were available because the NSF requires that ERCs report many types of outputs. The variables of most relevance to the two organizational outcome constructs, research publication productivity and technology commercialization productivity, were used to measure overall performance for each ERC.

Strategic plan formulation. In measuring the plan formulation, we were most interested in the extent to which a formal process of strategic planning occurred in the ERC and the quality of planning resulting from the formal process. Five items were used to measure existence of formal planning (Veliyath & Shortell, 1993). An example was: "My ERC holds strategic planning sessions throughout the year." Further, six items adapted from existing measures were used to measure the quality of planning (Kallman & Shapiro, 1978; Veliyath & Shortell, 1993). Examples included: "Long range plans (for more than one year ahead) for my ERC are prepared" and "Strengths and weaknesses of the ERC are systematically analyzed and considered when developing plans."

Commitment to the planning process and/or the three-plane framework. Commitment describes a situation in which an ERC truly accepts the framework and fully integrates use of it into its strategic planning processes. Level of commitment was measured using three items pertaining to the planning process and three items pertaining to the planning tool (Smith, Locke & Barry, 1990). Sample items included: "My ERC depends on a formal process to develop our plan" and, "My ERC has found the three-plane framework sufficiently useful so that it is used in non-ERC planning projects."

Organizational characteristics. Two organizational variables were measured: technological domain in which an ERC does research, and the time to commercializable product. The first variable, technological domain of the research, determines breadth of focus, or scope, of research. This was defined by four categories: bioengineering, manufacturing, earthquake, and information technology domains. ERCs were given a code based on the latest listing of ERCs and their content areas (*Engineering Research Centers*, 2005). The second variable was the length of time to engineered systems, or commercialization. This was a dichotomous variable defined by "pre-paradigmatic" (i.e., long time to commercializable product) or "paradigmatic" (i.e., short time to commercializable product). ERCs were coded based on categorizations provided by the ERC program leadership.

Attitudinal characteristics. Six constructs were included as attitudinal characteristics: acceptance of planning, perceived value of three-plane, knowledge of three-plane, perceived capability of three-plane to balance resources, professional commitment, and organizational commitment.

We wrote new survey items to measure the first four attitudinal variables. For acceptance of the tool, two items were used. A sample item is: "I have a positive opinion of the three-plane framework for use in strategic planning." Perceived value of the three-plane framework was measured using five items. Sample items were: "The three-plane framework is effective at focusing my ERC on its overarching goals" and "The three-plane framework provides an effective way to organize our thoughts in developing our strategic plan." Knowledge of the three-plane framework was measured by three items. A sample item was: "I have been trained on the use of the three-plane framework in strategic planning." Perceived capability of the three-plane to balance and re-balance resources was measured using three items. A sample item was: "The three-plane framework helps my ERC's leaders effectively re-allocate resources as needed."

Organizational commitment was measured using a 9-item scale which has been widely used (Aranya, Pollock & Amernic, 1981; Porter, Steers, Mowday & Boulian, 1974; Tetrick & Farkas, 1988). We amended the items to make the ERC the referent organization for each item. It contained items such as: "I am willing to put in a great deal of effort beyond that normally expected in order to help this ERC be successful," "I talk up this ERC to my friends as a great organization to be associated with," and "I would accept almost any type of job assignment in order to keep working with this ERC." Although we considered another commonly-used organizational commitment scale (Meyer et al., 2002), which measures normative, continuance, and affective commitment, we were primarily interested in the affective component of commitment to the organization. The Porter et al. scale used in the present study has been shown to have convergent validity with the affective items in the Meyer et al scale (Gist, Locke & Taylor, 1987). The scale we used measured three factors of commitment: belief in and acceptance of an organization's goals and values, readiness to exert considerable effort on behalf of the organization, and a desire to remain in the organization (Bline et al., 1991). These three factors describe the type of commitment we were most interested in, as we hypothesized relationships between organizational commitment and commitment to the planning process and tool.

Professional commitment was measured using an existing 7-item instrument where participants rate each statement on a 7-point scale from "Very Unimportant" to "Very Important" (Wang & Armstrong, 2004). Sample items included: "Build my professional reputation in my field," "Belong to the professional community of others in my field," and "Improve my knowledge in my field." We chose this scale because of its focus on measuring commitment to one's profession. We were most interested in the most prevalent type of commitment in the individuals associated with ERCs, either organizational or professional.

Statistical Power analysis. A power analysis was conducted using the average weighted effect size r, as reported in the literature (Ramanujam et al., 1986; Reid, 1989). Power analyses are typically conducted to determine if the study design is able to detect relationships where they exist. For example, power is too weak if a relationship exists between two variables but the study does not detect it. Power is usually adequate if a relationship is moderately strong, or if study includes enough participants. The typical effect size found in the extant strategic planning literature was .55, which is a large effect size according to Cohen et al. (2003). The resulting sample size needed to find this effect size, at a power of .80, was only 25. We studied 22 ERCs; therefore, our study had power close to .80, which is very acceptable according to the most common rule of thumb in the organizational literature.

Data analysis. Hierarchical Linear Modeling (HLM), multiple ordinary least squares (OLS) regression, and Poisson regression techniques were used to statistically analyze the data in this project (J. Cohen et al., 2003; Hofmann et al., 2000; Singer, 1998). HLM was used to analyze relationships between individual perceptions of commitment, acceptance of the tool, organizational structure and technology, and effective use of the three-plane framework and commitment to the process and/or tool. In these analyses HLM allowed us to analyze within- and between-group variances.

OLS, Poisson, and negative binomial regression were used to analyze the relationships between the aggregated,[2] individual-level variables and organizational level performance of the ERCs. These analyses allowed us to model between-group variance. This was appropriate because the dependent variables were counts at the organizational level (Hofmann et al., 2000), which Poisson and negative binomial regression are designed to analyze. OLS regression was used to analyze the relationship between the continuous variables.

Finally, path analysis was used to test hypothesized mediation. Shrout and Bolger's (2002) recommendations were followed to appropriately test the hypothesized mediators (commitment to process and/or tool and effectiveness of planning). These authors recommend a new, improved method to test for mediation, while building on a classic, widely-accepted method (Baron & Kenny, 1986).

[2] According to Rousseau (1985), variables must meet certain criteria to be appropriately aggregated. One of these criteria is a proper level of homogeneity as reflected in acceptable values of intra-class correlation (ICC) and within-group correlation (r_{wg}). Further, when the dependent variable is at the organizational level, it is a requirement to aggregate the individual-level variables to the level of the dependent variable to analyze relationships.

Appendix F: Technical Details of Statistical Analyses

As a first step, an exploratory factor analysis of survey items was completed using oblique rotation. Cronbach's alphas on the items in the survey were also calculated. These analyses were completed twice: once after the pilot survey and again after the full data collection from all ERCs. The results presented here are from the full data collection, not from the pilot (see Appendix G for full results of the reliabilities and factor analyses). As a result of the factor analyses, some items were dropped because they did not load appropriately on the intended constructs.

One issue that was resolved using factor analysis was the possible existence of a global commitment factor comprised of the items measuring commitment to the tool, commitment to the process, professional commitment, and organizational commitment. This analysis was necessary because of the similarity of the items and the common thread of commitment throughout these four constructs. The results of the factor analysis (shown in Appendix G, Table G4), revealed three factors, with organizational and professional commitment loading on separate factors and commitment to the tool and commitment to the process loading on one combined factor. However, when commitment to the tool and process were analyzed using a confirmatory two-factor model, the loadings on two factors justified keeping them as two separate factors (see Appendix G, Table G5). Although the loadings were rather low for all three factors, this analysis clearly delineated three factors and, therefore, ruled out the existence of a global commitment factor, which could have biased the results. The low factor loadings are most likely due to high inter-correlations among the three scales.

Missing data. Patterns of missing data were analyzed. Five independent variables had missing data patterns that significantly predicted two dependent variables. First, the missing data pattern of acceptance of the tool significantly predicted commitment to the process ($b=.47$, $p=.0002$). This statistic indicates that those who did not answer the acceptance of planning questions were more highly committed to the process of planning. Second, the missing data pattern of professional commitment significantly predicted strategic plan formulation ($b=.89$, $p=.04$). This statistic indicates that those who did not answer the professional commitment items felt that planning was more comprehensive at their ERC. Third, the missing data pattern of perceived value of the three-plane significantly predicted commitment to the process ($b=.34$, $p=.01$). This statistic indicates that those who did not answer the value of tool items were more committed to the process of planning. Fourth, the missing pattern of knowledge of the tool significantly predicted commitment to the process ($b=.25$, $p=.04$). This implies that those who failed to answer the knowledge items were also more committed to the process of planning. Finally, the missing pattern of perceived balancing capability of the three-plane significantly predicted commitment to the process ($b=.35$, $p=.004$). This also indicates higher commitment to the process in those respondents who did not answer the balancing capability items.

Because of these significant relationships, a multiple imputation procedure (i.e., PROC MI in SAS) was used to mathematically estimate missing values. Multiple imputation is recommended by statisticians in place of mean imputation, specifically when some missing data should be expected in the sample. Regression techniques are used to estimate scores for observations with partially missing data, based on non-missing responses on correlated variables. However, multiple imputation acknowledges that not all missing data should be estimated, based on the response patterns of each participant. Therefore, observations with all items missing on a particular construct scale are left with missing data. Conversely, scores are estimated for observations with partially complete scales (Tabachnick & Fidell, 2001). As a result, some missing data remained after the multiple imputation procedure was executed.

Next, the remaining missing data were analyzed for non-random missing patterns. This time, only the missing data pattern of acceptance of the three-plane framework significantly predicted one dependent variable, commitment to the tool (b=-1.09, p=.004). This implies that people who did not answer the acceptance to the tool items had lower levels of commitment to the tool. The 10 participants remaining with missing data on this construct were from seven different ERCs, represented three different categories of titles within the ERC, and were evenly distributed between male and female. Therefore, because the nonrandom missing data patterns indicated potential bias in non-response on this construct, and because deleting the observations did not alter sample size from any one ERC or demographic significantly, the 10 observations were deleted from the sample.

Finally, we considered the variables with acceptable, random missing data patterns. Multiple imputation was not deemed necessary for these variables because their missing patterns did not imply bias (i.e., they were randomly missing). The variables considered in this step were three dependent variables (i.e., commitment to the tool, commitment to the process, and strategic plan formulation) and one independent variable (i.e., organizational commitment). First, the number of missing items for each scale was analyzed. In general, when more than two items were missing on a scale, a variable score was not calculated. However, when two or fewer items were missing for these variables, the score was calculated based on the non-missing items. Decision rules varied slightly for each variable. Specifically, for strategic plan formulation, when at least 5 out of 7 items were answered, an average was taken for the variable. Otherwise, the variable score was left blank. For commitment to the tool and commitment to the process, when at least 2 out of 3 items each were answered, the same procedure was followed. For organizational commitment, when at least 7 out of 9 items were answered, the same procedure was followed. In all cases, when more than the minimum number of items was missing, the variable score was left as a missing value.

Once the variable scores were calculated, the observations were analyzed for missing variable scores, considering all the independent and dependent variables in the study, regardless of their original missing data pattern. Because an analysis cannot proceed with missing dependent variables, observations were kept in the sample only if they had data for all three dependent variables (i.e., commitment to the tool, commitment to the process, and strategic plan formulation). Further, observations with data on at least one independent variable were kept in the final sample.

After these procedures, the final sample size was 380, which was 17 percent of the total pool of those asked to complete the survey. Table 2 (in the main report) provides a breakdown of the demographics of the final sample used in the analyses.

Using the final sample, the data were screened for outliers and non-normality. Two indicators of normality, skew and kurtosis, are presented in Table F1. Ideal values are zero, which most variables are near. Negative skew indicates a clustering of values at the high end of the distribution. This means that a majority of the respondents scored above the neutral value of ‘4’ on each construct. Positive kurtosis indicates a more peaked distribution, with a majority of respondents scoring at one point in the distribution. The only exception to normality was professional commitment, which had a very high kurtosis statistic (9.10). This indicates a distribution with a very high narrow peak (Tabachnick & Fidell, 2001). This is not surprising since most of the respondents were faculty members or highly educated, professional workers. These types of workers tend to have a very high level of professional commitment (Wang & Armstrong, 2004). No extreme outliers were found in the dataset. All applicable outlier diagnostics, including DFFITS and Cooks D, were well within the range of acceptable values. Therefore, all observations were kept in the final dataset after the non-normality and outlier screening.

***Table F1.* Distribution Statistics**

Variable name	Skewness	Kurtosis
Strategic Plan Formulation	-1.13	1.92
Professional Commitment	-1.99	9.10
Organizational Commitment	-0.79	0.73
Commitment to the Three-Plane Framework	-0.10	0.13
Commitment to the Planning Process	-0.66	0.24
Acceptance of the Three-Plane Framework	-0.38	0.25
Perceived Value of the Three-Plane Framework	-0.41	0.28
Knowledge of the Three-Plane Framework	-0.68	-0.14
Perceived Capability of the Three-Plane Framework to Balance and Re-balance Resources	-0.33	-0.04

Next, correlations and descriptive statistics were calculated for all study variables. Means and standard deviations are reported in Table 3 (in the main report) for all study variables, including the individual components of each of the three dependent variables. Note that the starred variables are attitude variables measured by the survey and aggregated to the ERC level; the non-starred variables are archival ERC-level data. The final two variables, time to commercialization and technology domain, are dichotomous and categorical, respectively; the means and standard deviations for these indicate the approximate distribution of ERCs in each category.

The pooled within-group correlations of all variables are presented in Table F2. These represent the average correlations among study variables within each ERC. As seen in Table F2, most variables were at least moderately correlated with each other, with the exception of professional commitment. It is interesting to note that commitment to one's profession was weakly related to planning processes within the ERC, such as commitment to the strategic planning tool or process, or strategic plan formulation. This is not surprising for two reasons. First, professional commitment had little variance due to its high kurtosis statistic. Secondly, the administrative orientation of the other variables should prevent them from correlating highly with professional commitment. Taken together, the low correlations minimize the likelihood of mono-method response bias. This bias could occur when survey methodology is used to collect data for all attitudinal variables. When all variables are highly correlated with each other, mono-method bias is likely. However, because professional commitment was not highly correlated with other variables in this study, the possibility of mono-method response bias was reduced.

Individual-level correlations among the study variables, disregarding ERC groupings (total Pearson *r*'s), are presented in Table F3. These represent the total correlations for all individuals in the study. Differences were present in the correlations in Table F2 versus Table F3, when the multilevel nature of the data was ignored. The variable most affected was professional commitment, which was more highly correlated with the variables in Table F3 when ERC groupings were ignored than it was in Table F2. Overall, most variables were similarly correlated and maintained moderate to strong relationships. However, these results reiterate that the multilevel nature of the data is an important consideration.

Table F2. **Pooled Within-Group Inter-Correlations of Study Variables, at Individual Level**

	1	2	3	4	5	6	7	8	9
1. Strategic Plan Formulation	-								
2. Commitment to Three-Plane Framework	0.51**	-							
3. Commitment to Planning Process	0.76**	0.62**	-						
4. Organizational Commitment	0.57**	0.44**	0.50**	-					
5. Professional Commitment	0.17**	0.17**	0.13*	0.17**	-				
6. Acceptance of the Three-Plane Framework	0.39**	0.65**	0.48**	0.43**	0.05	-			
7. Value of Three-Plane Framework	0.40**	0.66**	0.51**	0.44**	0.07	0.76**	-		
8. Knowledge of Three-Plane Framework	0.47**	0.48**	0.38**	0.53**	0.12*	0.43**	0.40**	-	
9. Capability of Three-Plane to Balance and Rebalance Resources	0.50**	0.64**	0.57**	0.41**	0.10	0.66**	0.75**	0.38**	-

Note. * indicates p<.05; ** indicates p<.01. These are the average correlations within each ERC, at the individual level (n=378).

Table F3. **Total Inter-correlations of Study Variables, at Individual Level**

	1	2	3	4	5	6	7	8	9
1. Strategic Plan Formulation	-								
2. Commitment to Three-Plane Framework	0.51**	-							
3. Commitment to Planning Process	0.75**	0.62**	-						
4. Organizational Commitment	0.58**	0.43**	0.47**	-					
5. Professional Commitment	0.19**	0.15**	0.14**	0.22**	-				
6. Acceptance of Three-Plane Framework	0.42**	0.65**	0.45**	0.45**	0.07	-			
7. Value of Three-Plane Framework	0.44**	0.51**	0.71**	0.46**	0.10	0.77**	-		
8. Knowledge of Three-Plane Framework	0.47**	0.40**	0.52**	0.52**	0.16**	0.55**	0.52**	-	
9. Capability of Three-Plane Framework to Balance and Rebalance Resources	0.50**	0.54**	0.67**	0.40**	0.12*	0.65**	0.77**	0.48**	-

Note. * indicates p<.05; ** indicates p<.01. These correlations are the total r, at the individual level, not taking ERC into account (n=380).

Between-group correlations are reported in Table F4. Aggregated, ERC-level attitudinal variables (only those used in the Poisson regression analyses) and the count dependent variables are included in this correlation table. These aggregated variables represent conceptually different variables at the organization-level than they did at the person-level. Two interpretations of their aggregated meanings are possible. First, the aggregated variables could represent a culture of shared beliefs and opinions cultivated by the organization's leadership. Second, they could represent a conglomeration of like-minded individuals, not reinforced by the organization but by fellow workers. It is important to keep this distinction of construct meanings in mind when comparing organizational-level variables to individual-level variables. As with the individual-level correlations, the organizational-level attitudinal variables were somewhat highly correlated with each other.

***Table F4.* Between-group Inter-correlations of Study Variables**

	1	2	3	4	5
1. Average number of research outputs per year	-				
2. Average number of commercialization outputs per year	0.69**	-			
3. Strategic Plan Formulation	-0.04	-0.21**	-		
4. Commitment to the Three-Plane framework	-0.07	-0.54**	0.55**	-	
5. Commitment to the Planning Process	-0.15**	-0.47**	0.89**	0.78**	-

Note. * indicates p<.05; ** indicates p<.01. These correlations reflect all variables aggregated to the ERC level (n=22). Therefore these correlations are between-ERC correlations.

Technology domain was a four-category variable. Therefore analysis of variance was used to calculate Eta-squared, which is the amount of variance accounted for by technology domain in the two dependent variables hypothesized to be associated with it (Bliese, 2000). Technology domain accounted for one-half of one percent of the variance in commitment to the tool and for 4 percent of the variance in strategic plan formulation. Four percent is a small to moderate effect size, however one-half of one percent (0.5) is a very weak effect size (Cohen et al., 2003). Hence, technology domain was modestly associated with plan formulation but was not associated with commitment to the three-plane tool.

Technology commercialization is a central goal of the ERCs. Correlations of each individual component of technology commercialization effectiveness with the organizational-level, aggregated attitudinal variables were also calculated (see Table F5). This provides a more fine-grained analysis of the relationships. As seen in Table F5, the correlations of each individual component with the other variables differ from those of the composite effectiveness variables.

Time to commercialization and technology domain are hypothesized to be important characterizations for determining ERC planning activities so the correlations of all study variables within each of these categories were also calculated (see Tables F6-F11). These two variables are important considerations in this study and in future research, as correlations are very different in the six groups. This indicates that the length of time to commercializable product changes the relationships among effectiveness, planning, and other organizational attitudes. The same is true for the industry sector in which the ERC does research.

***Table F5.* Inter-correlations of Study Variables Including Components of Technology Commercialization**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Research Publications[a]	-														
2. Technology Commercialization[a]	.72**	-													
3. Invention Disclosures	.74**	.97**	-												
4. Patent Applications	.51**	.84**	.87**	-											
5. Patents Awarded	.46**	.87**	.87**	.82**	-										
6. Licenses	.65**	.58**	.66**	.69**	.54**	-									
7. Spin-offs	.60**	.67**	.75**	.63**	.58**	.31**	-								
8. Spin-off Employees	.58**	.87**	.75**	.52**	.65**	.17**	.51**	-							
9. Building Codes	-.05	-.15**	-.19**	-.19**	-.13*	-.12*	-.17**	-.08	-						
10. Technology Standards	-.05	-.15**	-.19**	-.19**	-.13*	-.12*	-.17**	-.08	1	-					
11. Medical Standards	.11*	-.10*	-.13*	-.11*	-.12*	-.11*	-.12*	-.07	-.05	-.05	-				
12. Comprehen-siveness of Planning	-.16**	-.20**	-.10*	-.28**	-.07	-.16**	-.02	-.19**	.20**	.20**	.13*	-			
13. Commitment to the Tool	-.27**	-.54**	-.44**	-.55**	-.33**	-.36**	-.26**	-.49**	.06	.06	.35**	.55**	-		
14. Commitment to the Process	-.27**	-.46**	-.38**	-.52**	-.29**	-.32**	-.23**	-.40**	.33**	.33**	.23**	.89**	.78**	-	
15. Technology Domain	.33**	.20**	.16**	.27**	.16**	.36**	.18**	.06	.11*	.12*	.33**	-.16**	-.34**	-.20**	-

Note. * indicates p<.05; ** indicates p<.01. These correlations are computed at the ERC level (n=22). Technology Domain is a categorical variable (1=Bioengineering, 2=Manufacturing, 3=Earthquake, 4=Information Technology). [a]Composite organizational outcomes.

Table F6. Inter-correlations of Study Variables for Pre-Paradigmatic ERCs only

	1	2	3	4	5	6	7	8	9	10	11	12
1. Research Publications[a]	-											
2. Technology Commercialization[a]	.54**	-										
3. Invention Disclosures	.72**	.94**	-									
4. Patent Applications	.45**	.99**	.89**	-								
5. Patents Awarded	.07	.82**	.62**	.86**	-							
6. Licenses	.95**	.65**	.77**	.57**	.17**	-						
7. Spin-offs	.78**	.80**	.89**	.75**	.53**	.74**	-					
8. Spin-off employees	.08	.88**	.69**	.90**	.93**	.25**	.50**	-				
9. Strategic Plan Formulation	-.12**	-.53**	-.36**	-.61**	-.71**	-.19**	-.34**	-.55**	-			
10. Commitment to Tool	-.09	-.73**	-.56**	-.72**	-.64	-.35**	-.25**	-.83**	.41**	-		
11. Commitment to Process	-.18**	-.79**	-.62**	-.84**	-.87	-.32**	-.46**	-.83**	.88**	.75**	-	
12. Technology Domain	.40**	.57**	.47**	.49**	.48**	.55**	.35**	.50**	-.24**	-.53**	-.44**	-

Note. * indicates p<.05; ** indicates p<.01. These correlations are computed at the ERC level (n=10). Technology Domain is a categorical variable (1=Bioengineering, 2=Manufacturing, 3=Earthquake, 4=Information Technology). [a]Composite organizational outcomes.

Table F7. Inter-correlations of Study Variables for Paradigmatic ERCs only

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Research[a]	-														
2. Commer-cialization[a]	.87**	-													
3. Invention Disclosures	.79**	.97**	-												
4. Patent Applications	.59**	.82**	.91**	-											
5. Patents Awarded	.66**	.89**	.96**	.93**	-										
6. Licenses	.45**	.56**	.62**	.80**	.67**	-									
7. Spin-off Companies	.47**	.63**	.69**	.54**	.66**	.07	-								
8. Spin-off Employees	.85**	.88**	.77**	.46**	.61**	.15**	.56**	-							
9. Building Codes	-.12*	-.20**	-.26**	-.27**	-.21**	-.16**	-.22**	-.11*	-						
10. Technical Standards	-.12*	-.20**	-.26**	-.27**	-.21**	-.16**	-.22**	-.11*	1	-					
11. Medical Standards	.12*	-.15**	-.18**	-.16**	-.20**	-.15**	-.16**	-.11*	-.10*	-.10*	-				
12. Compre-hensiveness of Planning	-.33**	-.11*	-.03	.004	.06	-.19**	.22**	-.16**	.21**	.21**	.10*	-			
13. Commit-ment to tool	-.61**	-.56**	-.49**	-.39**	-.38**	-.44**	-.30**	-.53**	.01	.01	.49**	.65**	-		
14. Commit-ment to process	-.58**	-.46**	-.39**	-.30**	-.30**	-.43**	-.08	-.43**	.40**	.40**	.22**	.88**	.78**	-	
15. Technology Domain	.20**	-.08	-.10*	.01	-.09	.24**	.02	-.17**	.11*	.11*	.47**	-.30**	-.26**	-.21**	-

Note. * indicates p<.05; ** indicates p<.01. These correlations are computed at the ERC level (n=22). Technology Domain is a categorical variable (1=Bioengineering, 2=Manufacturing, 3=Earthquake, 4=Information Technology). [a]Composite organizational outcomes.

Table F8. Inter-correlations of Study Variables for Bioengineering ERCs only

	1	2	3	4	5	6	7	8	9	10	11	12
1. Research Publications[a]	-											
2. Technology Commercialization[a]	.47**	-										
3. Invention Disclosures	.45**	.99**	-									
4. Patent Apps	.40**	.96**	.92**	-								
5. Patents Awarded	.18**	.89**	.85**	.90**	-							
6. Licenses	.21**	.96**	.94**	.94**	.97**	-						
7. Spin-off Companies	.89**	.73**	.73**	.60**	.45**	.53**	-					
8. Spin-off Employees	.83**	.23**	.27**	.07	-.18**	-.05	.73**	-				
9. Strategic Plan Formulation	-.26**	.36**	.41**	.29**	.44**	.49**	.17**	-.34**	-			
10. Commitment to the Tool	.65**	.79**	.71**	.83**	.75**	.71**	.74**	.17**	.24**	-		
11. Commitment to the Process	-.10*	.52**	.53**	.50**	.64**	.64**	.29**	-.36**	.94**	.53**	-	
12. Time to Commercialization	-.09	.79**	.76**	.81**	.95**	.93**	.25**	-.39**	.62**	.60**	.76**	-

Note. * p<.05; ** p<.01. These correlations are computed at the ERC level (n=6). [a]Composite organizational outcomes.

Table F9. Inter-correlations of Study Variables for Manufacturing ERCs only

	1	2	3	4	5	6	7	8	9	10	11	12
1. Research Publications[a]	-											
2. Technology Commercialization[a]	.98**	-										
3. Invention Disclosures	.99**	.99**	-									
4. Patent Apps	.95**	.94**	.95**	-								
5. Patents Awarded	.98**	.98**	.98**	.91**	-							
6. Licenses	.98**	.99**	.98**	.93**	.99**	-						
7. Spin-off Companies	.94**	.90**	.92**	.86**	.91**	.92**	-					
8. Spin-off Employees	.95**	.99**	.98**	.92**	.98**	.97**	.88**	-				
9. Strategic Plan Formulation	-.65**	-.69**	-.65**	-.78**	-.61**	-.64**	-.61**	-.68**	-			
10. Commitment to the Tool	-.90**	-.91**	-.91**	-.90**	-.87**	-.87**	-.75**	-.90**	.78**	-		
11. Commitment to the Process	-.95**	-.96**	-.96**	-.89**	-.93**	-.92**	-.91**	-.96**	.72**	.92**	-	
12. Time to Commercialization	.34**	.31**	.29**	.42**	.34**	.37**	.46**	.27**	-.20**	.01	-.15**	-

Note. * p<.05; ** p<.01. These correlations are computed at the ERC level (n=7). [a]Composite organizational outcomes.

Table F10. Inter-correlations of Study Variables for Earthquake ERCs only

	1	2	3	4	5	6	7	8	9	10	11
1. Research Publications[a]	-										
2. Technology Commercial-ization[n]	.37**	-									
3. Invention Disclosures	.31**	-.77**	-								
4. Patent Apps	.52**	.99**	-.65**	-							
5. Patents Awarded	-.31**	.77**	-1**	.65**	-						
6. Licenses	.98**	.17**	.50**	.33**	-.50**	-					
7. Building Codes	-.31**	.77**	-1**	.65**	1**	-.50**	-				
8. Technical Standards	-.31**	.77**	-1**	.65**	1**	-.50**	1**	-			
9. Comprehen-siveness of Planning	-.10*	.89**	-.98**	.80**	.98**	-.31**	.98**	.98**	-		
10. Commitment to the Tool	.01	.93**	-.95**	.86**	.95**	-.20**	.95**	.95**	.99**	-	
11. Commitment to the Process	-.24**	.81**	-.99**	.71**	.99**	-.44**	.99**	.99**	.99**	.97**	-

Note. * indicates p<.05; ** indicates p<.01. These correlations are computed at the ERC level (n=3). [a]Composite organizational outcomes.

Table F11. Inter-correlations of Study Variables for IT/Microelectronics ERCs only

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Research Publications[a]	-												
2. Technology Commercialization[a]	.27**	-											
3. Invention Disclosures	.48**	.95**	-										
4. Patent Apps	.19**	.99**	.91**	-									
5. Patents Awarded	-.22**	.74**	.69**	.77**	-								
6. Licenses	.66**	.60**	.72**	.57**	.41**	-							
7. Spin-off Companies	.32**	.45**	.57**	.37**	.23**	-.01	-						
8. Spin-off Employees	-.28**	.64**	.42**	.67**	.42**	-.20**	.45**	-					
9. Medical Standards	-.04	-.53**	-.56**	-.50**	-.51**	-.38**	-.41**	-.29**	-				
10. Strategic Plan Formulation	.15**	-.53**	-.30**	-.59**	-.26**	-.20**	.15**	-.63**	.47**	-			
11. Commitment to the Tool	.02	-.87**	.72**	-.88**	-.61**	-.31**	-.37**	-.82**	.70**	.81**	-		
12. Commitment to the Process	.10*	-.70**	.50**	-.74**	-.41**	-.26**	-.06	-.74**	.58**	.97**	.92**	-	
13. Time to Commercialization	-.03	-.12*	.001	-.12*	.28**	.05	-.05	-.38**	.49**	.74**	.52**	.69**	-

Note. * indicates p<.05; ** indicates p<.01. These correlations are computed at the ERC level (n=6). [a]Composite organizational outcomes.

Multilevel Model

A summary of the multilevel model statistics is presented in Tables F12 and F13. Hypotheses 1, 2, 4, 5, 6, 7, 8, 9, 10, and 11 were tested using multilevel modeling. These results were generated using PROC MIXED in SAS. Hierarchical Linear Modeling (HLM) is an analytical approach used in PROC MIXED. It is designed to take into account group membership (i.e., non-independence of responses due to group membership). It requires an individual-level dependent variable, but is used to analyze both individual- and organizational-level independent variables. Within HLM, we analyze between-group and within-group variance instead of ignoring the grouping of survey participants in their respective ERCs. In other words, in this study, the ERC was the group of interest. Therefore, 380 participants in 22 groups were analyzed.

In order to improve interpretability in the HLM analyses, scores for every participant were centered around each ERC group mean (Qu, 1997). After centering, the variance in the intercept represents the variance in the group means of the dependent variable. In other words, the intercept variance reflects how different the groups (i.e., ERCs) were in terms of each dependent variable. For each model tested, for each of the three dependent variables the random effects are presented in Table F12 and the fixed effects are presented in Table F13. Random effects represent the differences among ERCs in terms of means and slopes of the dependent variables, taking the independent variables into account. Fixed effects represent specific relationships between each independent variable and its respective dependent variable that were thought to hold across all ERCs. At a simplified level, fixed effects are interpreted as how ERCs are similar and random effects are interpreted as to how and why ERCs are different.

The first multilevel model tested was the unconditional means model. This analysis was used to estimate the total amount of between-group variance in the means of each dependent variable. This model was a baseline against which the more complex models were compared (Hoffman, 1997). For all three dependent variables, 6% of the total variance was between-ERC variance, as indicated by the intra-class correlation (ICC) in Table F14 (Bliese, 2000).

The second model tested was the conditional means model. This model included only ERC-level predictors and tested how much between-group variability in means was accounted for by the ERC-level predictors. Only commitment to the tool was hypothesized to have ERC-level predictors, therefore, it was the only dependent variable included in this step. Technology domain and time to commercialization were the two ERC-level predictors of commitment to the tool. As seen in Table F12, technology domain and time to commercialization accounted for essentially no between-group variance, indicated by the ICC, which remained unchanged between models 1 and 2.

In the third step, the individual-level effects were modeled. This model included only individual-level predictors and tested how much within- and between-group variance they accounted for. When the slopes and intercepts of the predictors vary across groups, this is referred to as the random coefficient regression model (Hoffman, 1997; Qu, 1997). In this study, only the perceived value of the tool showed significant variance across groups. As such, the rest of the independent variables were modeled as fixed effects only. Strategic plan formulation, commitment to the tool, and commitment to the process each had a great deal of within-ERC variance accounted for by their respective independent variables, as indicated by R^2 in Table F12 (R^2=54.9%, 46.8%, and 24.2%, respectively). One issue that arose in this analysis was the increase in the variance of the intercept, and, thus, in the ICC, when the individual-level effects model was tested.

Ordinarily, the intercept (i.e., the between-group variance indicator) decreases as variance gets accounted for by additional predictors. However, in this case it increased for all three independent variables.

Fixed effects are presented in Table F13. Organizational commitment (b=.17, p<.01), professional commitment (b=.16, p<.05), acceptance of the three-plane framework (b=.52, p<.01), knowledge of tool (b=12, p<.01), and perceived capability of the three-plane to balance and rebalance resources (b=.28, p<.01) each significantly predicted commitment to the three-plane framework. Organizational commitment was the only significant predictor of commitment to the process of planning (b=.51, p<.01). Therefore, hypothesis 4 was partially supported. Hypotheses 6, 8, and 9 were supported. These results suggest that commitment to the ERC as an organization is important for commitment to administrative processes inside the ERC, such as the planning process. Finally, commitment to the process of planning was the only significant predictor of strategic plan formulation (b=.57, p<.01). Therefore, hypothesis 2 was supported. These latter results suggest that as long as ERCs are committed to the process of planning, they may still plan well, even if they do not embrace the planning tool.

The fourth and final multilevel model tested was the mixed model. The mixed model included the combined effects of both person-level and organization-level predictors and analyzed how much within- and between-group variance was accounted for by the predictors. Again, commitment to the tool was the only dependent variable with organization-level predictors so it was the only dependent variable modeled in this step. Again, essentially no between-group variance in commitment to the tool was accounted for by the two organization-level predictors, as indicated by the ICC remaining unchanged between steps 3 and 4. As seen in Table F13, organizational commitment, professional commitment, acceptance of the three-plane tool, value of the tool, knowledge of the tool, and balancing capability of the tool all significantly predicted commitment to the three-plane tool (with the similar parameter estimates). Accordingly, in addition to hypotheses 6, 8, and 9, hypothesis 7 was supported by this step. Again, hypotheses 4 and 5 were partially supported and hypotheses 10 and 11 were not.

In sum, the HLM analyses revealed that the ERC-level predictors did not significantly predict commitment to the three-plane framework. However, organizational commitment, professional commitment, acceptance of the three-plane, value of the three-plane, knowledge of the three-plane, balancing capability of the tool, and commitment to the process all were important individual-level predictors of their respective dependent variables.

***Table F12.* Hierarchical Linear Modeling Statistics: Random Effects**

Model	Independent variables	Dependent variable	Value of Tool[c]	ICC	R^2	Residual[a]	Intercept[b]
Level 2, Unconditional Means Model (No IVs)	N/A	Commitment to the Three-Plane Framework		.06		1.26**	.08†
Level 2, Conditional Means Model (Level-2 IVs Only)	Technology Domain, Time to Commercializa-tion			.06	0%	1.26**	.08†
Level-1 IVs Only	Acceptance of the Tool, Organizational Commitment, Professional Commitment, Value, Knowledge, Balancing Capability		.24*	.20	61.1%	.49**	.12*
Mixed Model (All IVs)	Tech Domain, Time to Commercialization, Acceptance of the Tool, Org Commitment, Professional Commitment, Value, Knowledge, Balancing Capability		.08*	.19	58.7%	.52**	.12*
Level 2, Unconditional Means Model (No IVs)	N/A	Commitment to the Strategic Planning Process		.06		1.53**	.09†
Level-1 IVs Only	Organizational Commitment, Professional Commitment		-	.09	24.2%	1.16**	.11*
Level 2, Unconditional Means Model (No IVs)	N/A	Strategic Plan Formulation		.06		1.02**	.07*
Level-1 IVs Only	Commitment to the Tool, Commitment to the Process		-	.18	54.9%	.46**	.10**

Note. † indicates p<.10; * indicates p<.05; ** indicates p<.01. Level-2 Independent Variables are Time to Commercialization and Technology Domain. Level-1 Independent Variables are Organizational Commitment, Professional Commitment, and Acceptance of the 3-plane Tool. Refer to Figure 1. [a]Residual (σ^2) represents the within-ERC variance left unaccounted for (this is a raw value, not a percentage). [b]Intercept (τ_{00}) represents the between-ERC variance accounted for (this is a raw value, not a percentage). [c]Value of Tool is the only Level-1 independent variable whose slope varies significantly across ERCs, therefore, it is the only independent variable random effect reported. ICC=Percentage of total variance due to between-ERC variation after controlling for independent variables. R^2=Percentage of within-ERC variance explained by independent variables.

***Table F13.* Hierarchical Linear Modeling Statistics: Fixed Effects**

			Parameter estimates[b]											
Model	Dependent variable	Mean of DV	Time to commerc-ialization	Tech domain: bio[a]	Tech domain: manu[a]	Tech domain: e-quake[a]	Org commit-ment	Prof commit-ment	Accept-ance of the tool	Value of tool	Knowl-edge of tool	Balanc-ing capability of tool	Comm-itment to tool	Commit-ment to process
Level 2, Unconditional Means Model[c]	Commitment to the Three-Plane Framework	4.70**												
Level 2, Conditional Means Model[d]		4.42**	.34†	.28	.13	-.19								
Level-1 Model[e]		4.64**					.04	.17**	.18*	.18	.12**	.28**		
Mixed Model[f]		5.01**	.28	-.34	-.14	.10	.05	.15*	.20*	.20**	.12**	.22**		
Level 2, Unconditional Means Model[c]	Commitment to the Strategic Planning Process													
Level-1 Model[e]		5.06**					.51**	.04						
Level 2, Unconditional Means Model[c]	Strategic plan formulation	5.05**												
Level-1 Model[e]		5.45**											.07†	.57**

Note. † indicates p<.10; * indicates p<.05; ** indicates p<.01. [a]Each technology domain estimate is a comparison to the fourth category of the construct, IT/Electronics. [b]Unstandardized estimates. [c]Unconditional Means Model considers the dependent variable only, no independent variables are included. [d]Conditional Means Model includes only ERC-level (level-2) independent variables in the analysis. [e]Level-1 Model includes only individual-level independent variables. [f]Mixed Model includes all individual-level and ERC-level independent variables in the analysis

Mediation in Multilevel Model. Next, commitment to the tool and commitment to the process were tested as mediators between strategic plan formulation and the distal predictors (i.e., organizational commitment, professional commitment, acceptance of the tool, value of the tool, knowledge of the tool, balancing capability of the tool, time to commercialization, and technology domain). Results of this analysis are found in Tables F14 and F15. Mediation model notation was used as in Shrout & Bolger (2002). As indicated by the ICC in Table F14, the full model accounted for more between-group variance than any other model. Therefore, the full model appeared to best explain plan formulation.

Specific relationships in the full mediation model are presented in Table F15. The relationships between plan formulation and acceptance of the three-plane tool, professional commitment, and perceived value of the three-plane were fully mediated by commitment to the three-plane framework. Conversely, the relationships between organizational commitment, perceived balancing capability of the tool, and knowledge of the tool and plan formulation were partially mediated by both commitment to the three-plane framework and commitment to the planning process. In sum, commitment to the tool and commitment to the process were indeed mediators in the full model.

Table F14. **Post-hoc Hierarchical Linear Modeling Mediation Analyses: Random Effects**

Model	Independent variables	Mediator	Dependent variable	ICC	Residual[a]	Intercept[b]
X→Y	Technology Domain, Time to Commercialization, Acceptance of the Tool, Organizational Commitment, Professional Commitment, Value, Knowledge, Balancing Capability	Commitment to the Three-Plane Framework	Comprehen-siveness of Planning	.10	.54**	.06†
X→M				.19	.52**	.12*
M→Y				.11	.76**	.09*
X+M→Y				.10	.52**	.06†
X→Y	Organizational Commitment, Professional Commitment	Commitment to the Planning Process	Comprehen-siveness of Planning	.13	.62**	.09*
X→M				.09	1.16**	.11*
M→Y				.20	.44**	.11**
X+M→Y				.23	.37**	.11**

Note. † indicates $p<.10$; * indicates $p<.05$; ** indicates $p<.01$. Only full models including all applicable hypothesized variables were tested. [a]Residual (σ^2) represents the within-ERC variance left unaccounted for (this is a raw value, not a percentage). [b]Intercept (τ_{00}) represents between-ERC variance accounted for (this is a raw value, not a percentage). ICC=Percentage of total variance due to between-ERC variation after controlling for independent variables.

Table F15. **Post-hoc Hierarchical Linear Modeling Mediation Analyses Results: Fixed Effects**

			Parameter estimates												
Model[a]	Mediator	Dependent variable	Mean of DV	Time to comer-cializa-tion	Tech domain[b]: bio	Tech domain[b]: manu	Tech domain[b]: e-quake	Org commit-ment	Prof commit-ment	Accept-ance of the tool	Value of tool	Knowl-edge of tool	Balanc-ing capabil-ity of tool	Commit-ment to tool	Commit-ment to process
X→Y	Commitment to the 3-plane Framework	Strategic Plan Formulation	5.33**	.23	.12	.28	-.18	.31**	.09	-.01	-.07	.11**	.27**		
X→M			4.39**	.28	-.34	-.14	.10	.05	.15*	.20*	.12**	.22**	-.12		
M→Y			5.55**											.48**	
X+M→Y			5.33**	.24†	.12	.29†	-.17	.31**	.06	-.05	-.11†	.09*	.23**	.20**	
X→Y	Commitment to the Process	Strategic Plan Formulation	5.51**					.44**	.09						
X→M			5.05**					.51**	.04						
M→Y			5.53**												.60**
X+M→Y			5.53**					.23*	.07						.51**

Note. † indicates p<.10; * indicates p<.05; ** indicates p<.01. [a]Mediation model notation as used in Shrout & Bolger (2002); X=Independent Variable, M=Mediator, Y=Dependent Variable. Only full models including all applicable hypothesized variables were tested. [b]Technology domain estimates are each a comparison to the fourth category of the construct, IT/Electronics.

Statistical Models Using Count Data Dependent Variables

To this point, organizational outcomes, which were measured by two separate count variables, were not included in the analyses because they were organizational-level dependent variables. Therefore, we used OLS regression, Poisson, and negative binomial regression to analyze the relationship between organizational outcomes and respective predictors. The hypothesized relationship among these variables included a mediator and strategic plan formulation. Shrout and Bolger's (2002) recommendations were followed in testing for mediation. Hypotheses 1, 2, and 3 were tested using in this procedure.

Because the dependent variable was at the organizational level, all predictors were aggregated to that level. Thus, the constructs tested in this step were conceptually different than those tested in HLM, because of the level of analysis. In addition to aggregating all variables to the ERC-level, we centered the ERC means around the grand mean in order to improve interpretability. Ordinary least squares (OLS) regression was used to regress strategic plan formulation on the independent variables because these were continuous and normally distributed. However, the organizational outcomes dependent variables were count variables; therefore, they were non-normal and bounded on the low end by zero. Negative binomial regression was the preferred analysis method for this type of dependent variable, because, like Poisson regression it is appropriate for count dependent variables, yet has fewer assumptions. Specifically, Poisson regression assumes that occurrence of the dependent variable is a random event (e.g., that observations are equally likely to have an occurrence of each dependent variable). In this study, ERCs have differing levels of success and are likely non-random in their ability to reach their goals. ERCs with more industrial support may be more likely to have technology transfer, for example. This non-randomness causes biased, liberal significance tests and it manifests itself in the "deviance per degrees of freedom" statistic in that, if Deviance/DF is greater than one, it indicates over-dispersion. This is the case for all three composite effectiveness dependent variables. Because of this violation of the Poisson regression assumption, we used negative binomial regression, which is not subject to the assumptions of Poisson. However, when over-dispersion is not present, the results of the two methods are usually nearly identical (Currall et al., 1999). The results of the negative binomial regression analyses are presented in Table F16.

Two dependent variables were analyzed separately: research publication productivity and technology commercialization productivity. In the first step of the mediation analysis, each dependent variable was regressed directly on the two distal independent variables: commitment to the tool and commitment to the planning process. Here, neither commitment to the tool nor commitment to the process significantly predicted technology commercialization. However, the mediation method proposed by Shrout and Bolger (2002) does not require any significant relationships in this first step for mediation to occur. This means that after this step, the variables were still eligible for a mediated relationship.

In the second step of the mediation analysis, the mediator, strategic plan formulation, was regressed on commitment to the tool and commitment to the process (using OLS regression). Here, both independent variables significantly predicted plan formulation. Commitment to the tool was negatively associated with planning ($b=-.27$, $p<.05$) and commitment to the process was positively associated with planning ($b=.86$, $p<.01$). This implies that for every unit increase in commitment to the tool, comprehensiveness of strategic plan formulation decreases by .27 units. Conversely, for every unit increase in commitment to the planning process, comprehensiveness of strategic plan formulation increases by .86 units. In the third step of the mediation analysis, each dependent variable was regressed on the plan formulation. None of the three dependent variables was able to significantly predict plan formulation.

In the fourth and final step of the mediation analysis, each dependent variable was regressed on all predictors including the mediator. With all independent variables in the model, plan formulation was still insignificant in predicting research publication productivity. However, plan formulation (b=5.08, $p<.05$) fully mediated the relationship between commitment to the three-plane tool and commercialization effectiveness, and partially mediated the relationship between commitment to the planning process (b=4.82, $p<.05$) and technology commercialization productivity. In this full model, the direction of the effects of commitment to the process and commitment to the tool on effectiveness remained negative while the direction of the effect of plan formulation on effectiveness was positive. This indicates that lower levels of commitment to the planning process and/or tool, but higher levels of comprehensiveness of plan formulation led to more technology commercialization effectiveness. Therefore, hypothesis 3 was partially supported. In sum, the negative binomial regression analyses provided evidence that strategic plan formulation is a mediator between the independent variables and technology commercialization productivity. Refer to Table F16 for a full report of these statistics.

As a final post-hoc analysis, the specific components of each organizational outcome were analyzed separately using negative binomial regression, or Poisson regression, as appropriate (see Table F17). The results were very similar to the composite organizational outcome results. Neither of the research publication productivity indicators was significantly associated with any independent variables. However, technology commercialization productivity showed different results for different specific indicators. Therefore, these results are potentially more informative when considering the impact planning has on specific indicators of ERC effectiveness.

The two full models with resulting parameter estimates are presented in Figures F1 and F2. The results of the post-hoc mediation analyses performed in HLM, using the individual and ERC-level variables, are presented in Figure F1. The results of the Poisson and negative binomial regression mediation analyses, using aggregated ERC-level variables, are presented in Figure F2.

In summary, hypothesis 1 was not supported, as commitment to the three-plane negatively impacted plan formulation. However, hypothesis 2 was supported. Hypothesis 3 was partially supported, because research publication productivity was not impacted by strategic planning. But, technology commercialization productivity was positively impacted by plan formulation. Hypothesis 4 was partially supported, as organizational commitment was only associated with commitment to the process. Hypothesis 5 was not supported, but professional commitment was significantly, positively associated with commitment to the tool. Hypotheses 6, 7, 8, and 9 were fully supported. Finally, hypotheses 10 and 11 were not supported.

***Table F16.* Negative Binomial and Ordinary Least Squares Regression Analyses Results**

Dependent variable	Model	Deviance/DF[a]	Commitment to the three-plane tool	Commitment to the planning process	Strategic plan formulation
Average Research Outputs per Year	X→Y	1.3	-.11	-.52	
Strategic Plan Formulation (R^2 = .84, F=48.18**)[b]	X→M		-.27*	.86**	
Average Research Outputs per Year	M→Y	1.2			-.51
Average Research Outputs per Year	X+M→Y	1.3	.17	-1.30	.95
Average Commercialization Outputs per Year	X→Y	1.4	-.62	-.57	
Strategic Plan Formulation (R^2 = .84, F=48.18**)[b]	X→M		-.27*	.86**	
Average Commercialization Outputs per Year	M→Y	1.3			-.81
Average Commercialization Outputs per Year	X+M→Y	1.5	.80	-4.82*	5.08*

Note. * indicates p<.05; ** indicates p<.01. The mediator is Strategic Plan Formulation. Negative Binomial has fewer assumptions than Poisson regression but is otherwise a similar analysis. Negative binomial regression, is more suitable for over-dispersed distributions. [a]Deviance/DF = 1 indicates ideal; Deviance/DF < 1 indicates underdispersion; Deviance/DF > 1 indicates overdispersion. [b]Ordinary least square regression.

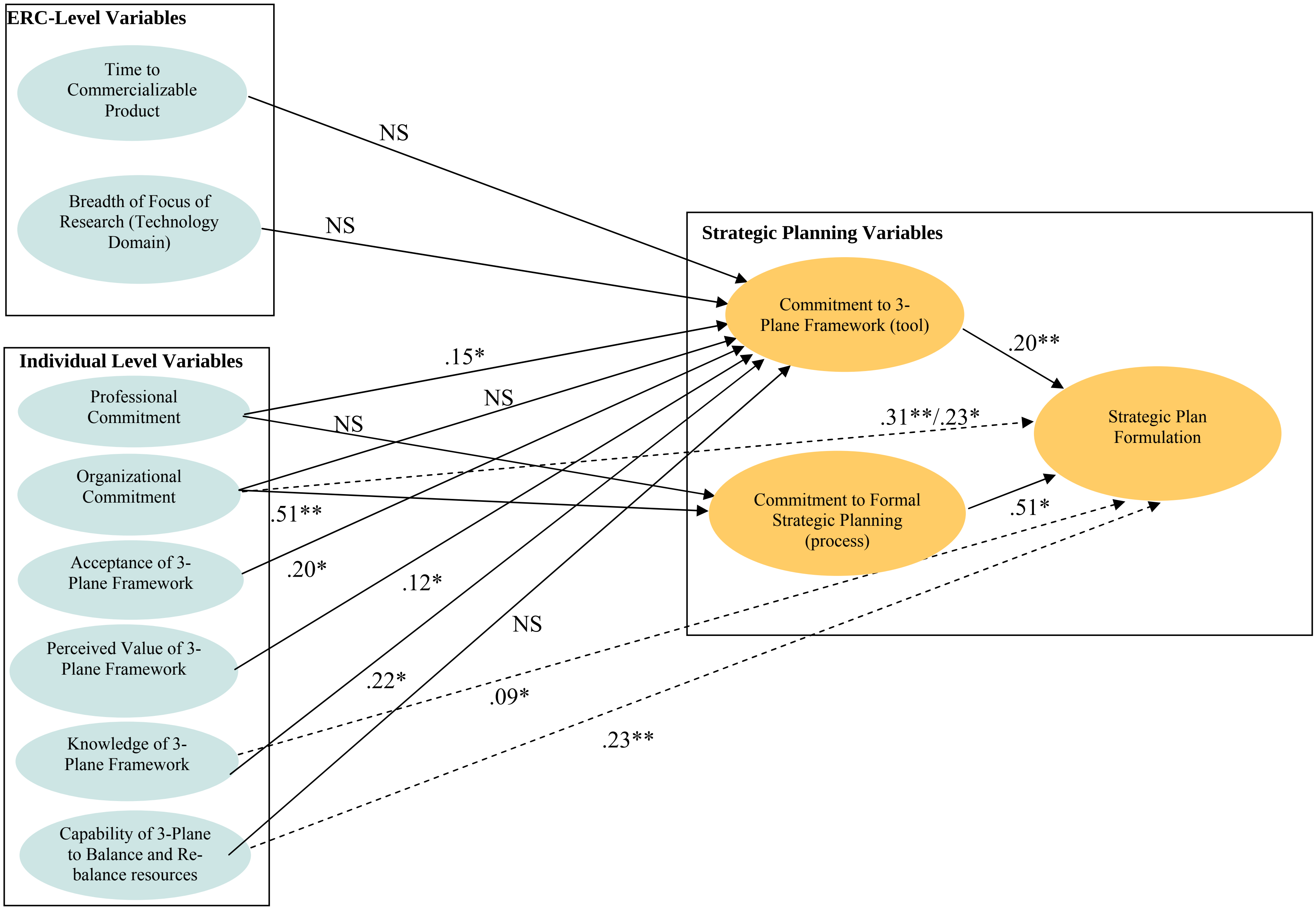
***Table F17.* Post-hoc Negative Binomial Regression Results for Individual Components of 2 Dependent Variables**

			Parameter Estimates		
Dependent variable	Model tested	Deviance/DF[a]	Commitment to the three-plane tool	Commitment to the process	Strategic plan formulation
Tech Journals - publications	M→Y	1.2			-.18
	X→Y	1.2	.18	-.41	
	X+M→Y	1.3	.45	-1.17	.95
Peer-reviewed Journals- publications	M→Y	0.9			1.59
	X→Y	0.9	2.19	.19	
	X+M→Y	1.0	4.40	-8.78	10.15
Conference Proceedings- publications	M→Y	1.3			-.88
	X→Y	1.4	-.39	-.59	
	X+M→Y	1.4	-.21	-1.09	.59
Invention Disclosures – tech commercialization	M→Y	1.3			-.27
	X→Y	1.4	-.51	-.34	
	X+M→Y	1.4	1.07	-5.07*	5.43*
Patent Apps – tech commercialization	M→Y	1.3			-.76
	X→Y	1.4	-.13	-.74	
	X+M→Y	1.4	.71	-3.55†	3.35
Patents Awarded – tech commercialization	M→Y	1.2			-.16
	X→Y	1.3	-.37	-.29	
	X+M→Y	1.3	1.23	-5.04*	5.48*
Licenses – tech commercialization	M→Y	1.2			-1.49
	X→Y	1.3	-.15	-1.66	
	X+M→Y	1.3	1.06	-6.41*	5.84*
Spin-off Companies – tech commercialization	M→Y	1.0			.05
	X→Y	1.1	-.34	-.24	
	X+M→Y	1.1	1.45	-5.02†	5.39†
Spin-off Company Employees – tech commercialization	M→Y	0.9			-2.33
	X→Y	0.9	-2.57	-1.04	
	X+M→Y	1.0	1.27	-9.39	9.43
Building Standards Impacted (Poisson) – tech commercialization	M→Y	0.2			4.89†
	X→Y	-	-	-	
	X+M→Y	-	-	-	-
New Technical Standards (Poisson) – tech commercialization	M→Y	0.9			4.89†
	X→Y	-	-	-	
	X+M→Y	-	-	-	-

Dependent variable	Model tested	Deviance/DF[a]	Parameter Estimates: Commitment to the three-plane tool	Commitment to the process	Strategic plan formulation
New Medical Standards (Poisson) – tech commercialization	M→Y	0.2			7.44
	X→Y	0.8	7.34**	2.77	
	X+M→Y	0.7	6.70**	7.28*	-4.92

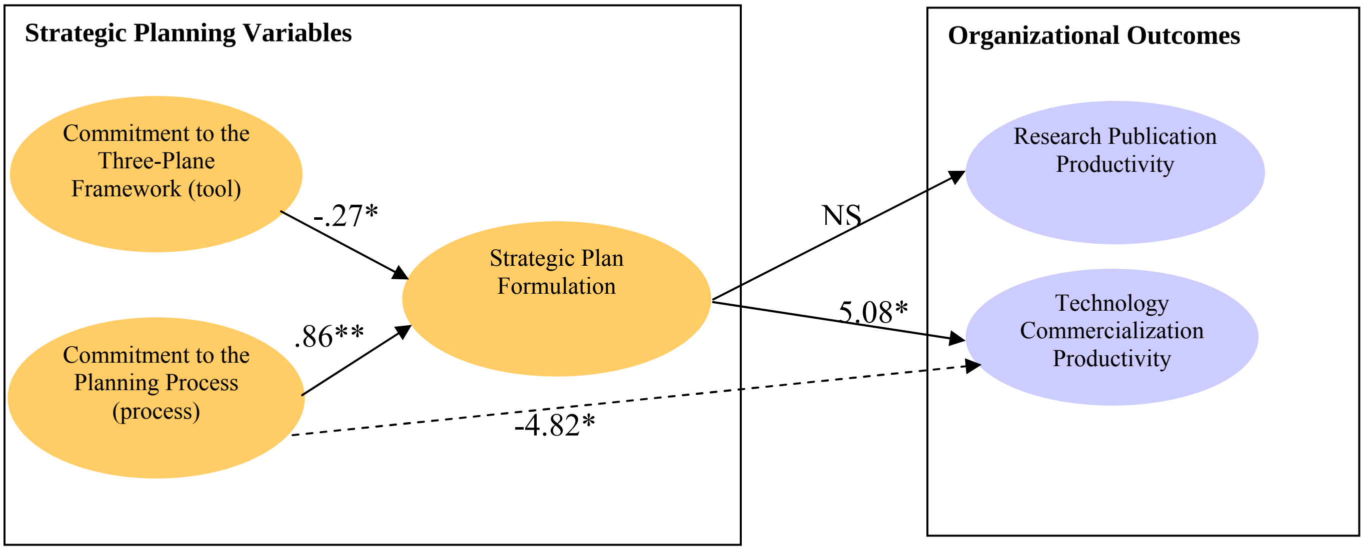
Note. † indicates p<.10; * indicates p<.05; ** indicates p<.01. Dashes indicate data that could not be calculated due to insufficient available data. [a]Deviance/DF = 1 indicates ideal; Deviance/DF < 1 indicates underdispersion; Deviance/DF > 1 indicates overdispersion.

Figure F1. **Resulting Model from Multilevel Analyses**



Note. * indicates p<.05; ** indicates p<.01; NS indicates non-significant. Dashed lines represent non-hypothesized direct effects.

Figure F2. **Resulting Model from Negative Binomial Analyses**



Note. * indicates p<.05; ** indicates p<.01; NS indicates non-significant. Dashed lines represent relationships that emerged but were not hypothesized.

Appendix G: Item and Construct Analyses Results

***Table G1.* Standardized Cronbach Alphas**

Variable Name	Standardized Cronbach's Alpha
1. Strategic Plan Formulation	0.91
2. Commitment to Planning Process	0.87
3. Commitment to Three-Plane Framework	0.79
4. Organizational Commitment	0.93
5. Professional Commitment	0.90
6. Acceptance of Three-Plane Framework	0.83
7. Organizational Structure (Dropped)	0.57
8. Value of Three-Plane Framework	0.94
9. Knowledge of Three-Plane Framework	0.92
10. Capability of Three-Plane Framework to Balance and Rebalance Resources	0.96

***Table G2.* Acceptance of Three-Plane Framework Factor Loadings**

Variable Name	Standardized Factor Loadings
	Factor 1
1. Acceptance of Tool – Item 1 "People in my ERC have a positive opinion of the three-plane framework for use in strategic planning."	0.49
2. Acceptance of Tool – Item 2 "I have a positive opinion of the three-plane framework for use in strategic planning."	0.49

Note. Seven-point response scale where 1=Strongly disagree and 7=Strongly agree.

***Table G3.* Commitment Factor Loadings**

Variable Name	Standardized Factor Loadings		
	Factor 1	Factor 2	Factor 3
1. Organizational Commitment – Item 7 "I am extremely glad that I chose this ERC to work with."	0.19		
2. Organizational Commitment – Item 5 "I am proud to tell others that I am part of this ERC."	0.16		
3. Organizational Commitment – Item 6 "This ERC really inspires the very best in me in the way of job performance."	0.19		
4. Organizational Commitment – Item 2 "I talk up this ERC to my friends as a great organization to be associated with."	0.15		
5. Organizational Commitment – Item 9 "For me, this ERC is the best of all possible organizations with which to work."	0.14		
6. Organizational Commitment – Item 4 "I find that my values and the ERC's are very similar."	0.11		
7. Organizational Commitment – Item 1 "I am willing to put in a great deal of effort beyond that normally expected in order to help this ERC be successful."	0.08		
8. Organizational Commitment – Item 8 "I really care about the fate of this ERC."	0.05		
9. Organizational Commitment – Item 3 "I would accept almost any type of job assignment in order to keep working with this ERC."	0.05		
10. Professional Commitment – Item 5 "Keep contact with others in my profession."		0.28	
11. Professional Commitment – Item 1 "Build my professional reputation in my field."		0.26	
12. Professional Commitment – Item 6 "Earn respect in the eyes of colleagues in my field outside my employing organization."		0.16	
13. Professional Commitment – Item 3 "Improve my knowledge in my field."		0.14	
14. Professional Commitment – Item 2 "Belong to the professional community of others in my field."		0.10	

Variable Name	Standardized Factor Loadings		
	Factor 1	Factor 2	Factor 3
15. Professional Commitment – Item 4 "Have adequate career prospects within my chosen profession."		0.10	
16. Professional Commitment – Item 7 "Have an adequate level of salary relative to colleagues in my field outside my employing organization."		0.12	
17. Commitment to the Tool – Item 1 "My ERC depends on the three-plane framework to develop our strategic plan."			0.26
18. Commitment to the Process – Item 3 "My ERC places a high priority on strategic planning sessions."			0.23
19. Commitment to the Process – Item 1 "My ERC depends on a formal process to develop our strategic plan."			0.16
20. Commitment to the Process – Item 2 "My ERC is enthusiastic about strategic planning."			0.24
21. Commitment to the Tool – Item 2 "My ERC has found the three-plane framework sufficiently useful so that it is used in non-ERC planning projects."			0.11
22. Commitment to the Tool – Item 3 "My ERC has customized the three-plane framework in order to tailor it to our ERC's unique needs and/or characteristics."			0.12

Note. Seven-point response scale where 1=Strongly disagree and 7=Strongly agree.

***Table G4.* Commitment to the Tool and Process Factor Loadings**

Variable Name	Standardized Factor Loadings	
	Factor 1	Factor 2
1. Commitment to the Process – Item 3 "My ERC places a high priority on strategic planning sessions."	0.53	
2. Commitment to the Process – Item 2 "My ERC is enthusiastic about strategic planning."	0.31	
3. Commitment to the Process – Item 1 "My ERC depends on a formal process to develop our strategic plan."	0.15	
4. Commitment to the Tool – Item 1 "My ERC depends on the three-plane framework to develop our strategic plan."		0.46
5. Commitment to the Tool – Item 3 "My ERC has customized the three-plane framework in order to tailor it to our ERC's unique needs and/or characteristics."		0.30
6. Commitment to the Tool – Item 2 "My ERC has found the three-plane framework sufficiently useful so that it is used in non-ERC planning projects."		0.21

Note. Seven-point response scale where 1=Strongly disagree and 7=Strongly agree.

***Table G5.* Strategic Plan Formulation Factor Loadings**

Variable Name	Standardized Factor Loadings	
	Factor 1	Factor 2
1. Existence of Planning – Item 5 "My ERC revisits the process of strategic planning yearly."	0.20	
2. Existence of Planning – Item 2 "My ERC had a defined mission and the strategic plan reflects that mission."	0.19	
3. Existence of Planning – Item 4 "My ERC articulates its goals and strategic plans to all persons affiliated with the ERC."	0.16	
4. Existence of Planning – Item 1 "My ERC holds strategic planning sessions throughout the year."	0.11	
5. Existence of Planning – Item 3 "My ERC has sufficient involvement in the strategic planning process from all persons affiliated with it."	0.12	
6. Effectiveness of Planning – Item 1 "Long range plans (for more than one year ahead) for my ERC are prepared."	0.12	
7. Effectiveness of Planning – Item 2 "Strengths and weaknesses of the ERC are systematically analyzed and considered when developing plans."	0.13	
8. Effectiveness of Planning – Item 4 "The market trends applicable to our ERC research are analyzed and forecasted as input to the planning process." (Dropped)		0.53
9. Effectiveness of Planning – Item 3 "Industry support trends are analyzed and forecasted as input to the planning process." (Dropped)		0.28
10. Effectiveness of Planning – Item 5 "Alternate courses of action for each goal are thoroughly evaluated." (Dropped)		0.25
11. Effectiveness of Planning – Item 6 "My ERC's strategic planning process would benefit from more involvement of all members and participants in this ERC." (Dropped)	0.02	-0.02

Note. Seven-point response scale where 1=Strongly disagree and 7=Strongly agree.