9-2016

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Elizabeth Carole Gibson
Portland State University

Tugrul U. Daim
Portland State University, tugrul@etm.pdx.edu

Citation Details

E. Gibson and T. U. Daim, "A measurement system for science and engineering research center performance evaluation," 2016 Portland International Conference on Management of Engineering and Technology (PICMET), Honolulu, HI, 2016.

A Measurement System for Science and Engineering Research Center Performance Evaluation

Elizabeth Gibson, Tugrul U. Daim
Portland State University, Portland, OR - USA

Abstract--**This research is focused on gaining deeper insights into US National Science Foundation (NSF) science and engineering research center challenges and motivated to develop a method that effectively measures the performance of these organizations. While research has addressed organizational performance at the micro, or single-actor level for universities or companies and at the regional or national macro level, the middle level where the NSF centers reside is largely missing. The bulk of the cooperative research center studies use either case-based methods or bibliometric data to measure traditional research outputs. Many are excellent studies; however, they only focus on a piece of the performance measurement problem. There is a need for more research to understand how to measure performance and compare performance of cooperative research centers formed in a triple-helix type partnership involving government, industry and academia. This research begins to fill these gaps by examining outputs from a balanced perspective and introducing a hierarchical decision model that uses both quantitative and qualitative metrics for a holistic study. The proposed outcome of this research is a performance measurement scoring system that can be used for science and engineering focused research centers. The method is demonstrated using the NSF IUCRC model.**

I. INTRODUCTION

Increasing U.S. public policy support for multi-disciplined research and technology transfer initiatives has resulted in the evolution of many different forms of technology transfer mechanisms [1]. The plethora of literature studying the impact of these policies has led researchers to claim we are in "the era of inter-institutional research collaboration" [[2] p 975]. So, it is not surprising that today, university-based research centers "are prevalent as both policy mechanisms and industry strategies" [[3] pg 76]. Cooperative research centers (CRCs) that involve partnership agreements with actors from three different sectors of government, academia and industry are often referred to as a "triple-helix" [4] or a government-university-industry (GUI) [5] collaboration. Public policies will most likely continue to support GUI CRCs because industry-university collaborations and multi-disciplinary research is required to solve increasingly complex social problems [6]. While there are many types of technology transfer mechanisms, literature shows that the most sustainable mechanisms require industry-sponsored collaborative research [7].

The National Science Foundation (NSF) is responsible for technology planning and science and engineering based research and education in the United States. Recognizing the value of industry sponsored cooperative research, the NSF launched a program in 1980 to improve the linkage between industry and university for cooperative research [8]; now known as the Industry-University Cooperative Research Center (IUCRC) program. The success of this model led to the development of other NSF science and engineering centers. Because the model has been replicated multiple times, the social technology clarifies the unit of analysis making it a better candidate for study than other CRCs. Today, over 66 IUCRCs are actively supported by the NSF. Literature shows the IUCRC to be one of the more successful CRCs [9].

Academia, policy makers [10] and CRC managers are all invested in understanding the performance and impact of these centers [11]. "The growth in private and public investment in university-based technology initiatives has raised important policy questions" [[12] p 254]]. The majority of research studies on performance evaluation of CRC's use qualitative case-based methods or quantitative methods based on traditional indicators such as patents and publications. Despite the effort and many excellent studies, researchers are cautioning that traditional measures are "wrong" [14] or inadequate [15] placing a call-to-arms for further research. A multi-dimensional-holistic study with a flexible approach that can evaluate both quantitative and qualitative output indicators is needed [16].

This study examines the literature to explore the concerns about current indicators and measurement systems. It adds value by exploring and presenting a balanced approach to using output indicators by developing a flexible measurement system incorporating qualitative and quantitative metrics. A generalizable model is developed that produces a score to evaluate and compare the effectiveness in which a center is achieving the NSF program's mission.

Including this introduction, the paper is organized into 6 sections. Section 2 reviews the academic literature on national planning of technology and cooperative research center program evaluation. Section 3 summarizes the research gaps identified in section 2 and identifies the need for a holistic performance evaluation model. Section 4 discusses organizational effectiveness and introduces a framework to characterize concepts and link them together to construct a model. A generalizable hierarchical decision model (HDM) is developed and discussed by applying the concepts to the NSF IUCRC program. Section 5 outlines directions of future research and section 6 summarizes the discussion and concludes the paper.

II. LITERATURE REVIEW

A comprehensive review of the academic literature on US technology planning and cooperative research center (CRC) performance evaluation was conducted. This large and complex topic warrants the use of a framework. Figure 1 shows how Ruegg and Feller's evaluation logic model [17] was adapted to organize and discuss the literature review using a top-down approach.

Societal goals change throughout time. During the 1940's and 1950's, US interest in national technology foresight activities increased as a result of successful cooperative research projects achieved during WWII [18]. Competing for supremacy during the Cold War drove further technology development in national defense and space exploration programs [19]. Then, global economic competition and the recession encouraged commercialization of the defense industry [20]. Large government research organizations began to use a collaborative technology foresight approach to complement their strategic planning processes [21].

Technology foresight is a process that systematically looks into the future to examine areas of research and emerging technologies [22]. Martin originally defined foresight as a systematic process to look into the longer-term future of science and technology for strategic research identification [23]; however, Coates [24] and others [25] expanded the definition to include a shift towards participative approaches to create shared longer-term vision to support short-term, decision-making processes about national initiatives. It has also been defined as a tool in policy and strategic planning [26], [27], for priority setting and decision making [28] and for creation of vision and pursuit of knowledge [29], [30] to solve complex socio-technical problems. Geels explains how a multi-level-perspective (MLP) is required to effectively transition technology to solve "socio-technical" system problems [31] because they not only entail technologies but also markets and cultural meanings [32].

Public policy strategies are often the result of national foresight activities [33]. While policies have long focused on facilitating collaboration among industry and academia [1][34][35][36], in the 1980's the US national research agenda began to place more focus on technology transfer.

- 1980: The Bayh-Dole Act permits universities to obtain title and license to inventions generated with projects funded by the government [37],
- 1984: The Cooperative Research Act supports the engagement of universities and federal laboratories to conduct joint pre-competitive R&D projects [13].
- 1993: The Government Performance and Results Act requires codification of the use of quantitative metrics for program evaluation [19].
- 2010: America Competes Act Reauthorization supporting linkages between research investments and economic growth and societal benefits [38]

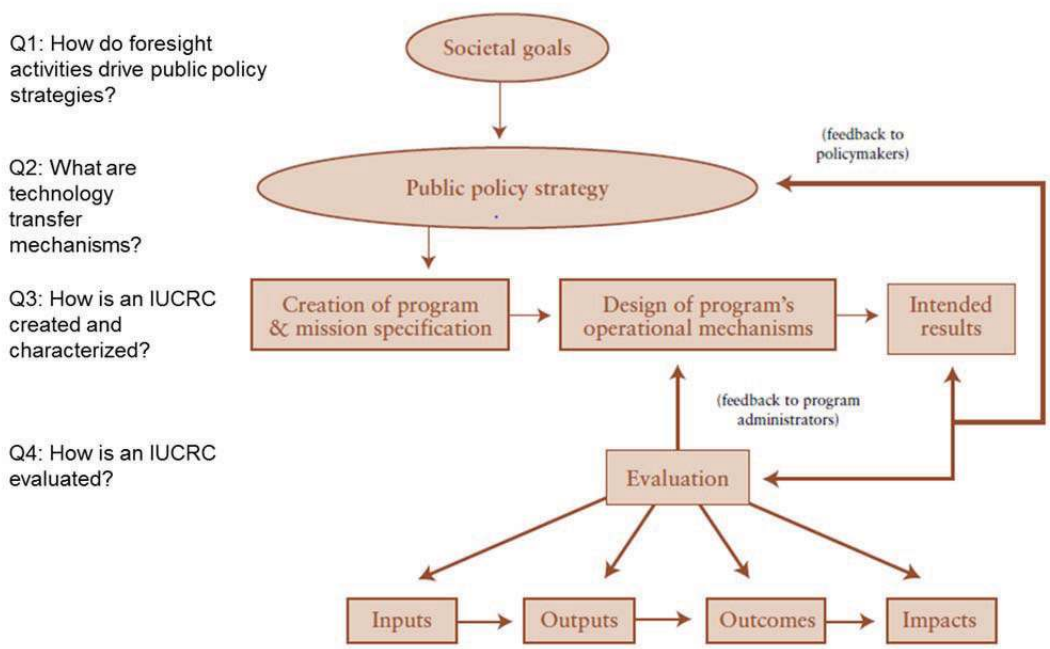

Figure 1: Generic Evaluation Logic Model [17]

Roessner defines technology transfer as "the movement of know-how, technical knowledge, or technology from one organizational setting to another" [39]. Interested in further supportive policies, government started looking for practical organizational structures [40][41] that encouraged knowledge and technology transfer [42] having a significant impact on CRC programs [43].

A. Cooperative Research Centers (CRCs)

Today, GUI CRC's are a popular technology transfer mechanism [9][44] because industry-sponsored collaborative research [7] is an important business model component for sustainable innovations [45]. "Increasingly, firms are bypassing traditional mechanisms (e.g. contracts, gifts) and providing support through industry/university (I/U) linkage mechanisms" [[46] p 5]. Public funding has also increased driving more concern for evaluation of these programs.

As a result, the GUI CRC evaluation literature is increasing rapidly [47]. Bozeman named a stream of literature the "cooperative technology policy paradigm" because it "features an active role for government actors and universities in technology development and transfer" [[48] p 632]. However CRC's are "inherently complex and therefore a challenging phenomenon to understand" [[6] p 5] requiring a systems perspective [49].

While there is still some debate about what constitutes a CRC, Boardman and Gray define a CRC in terms of three characteristics:

- it has an organizational structure and exhibits "organizational formality",
- engages in research, and
- promotes external, "cross-sector collaboration and transfer" [[6] p 451].

B. Gaps

Despite the research interest and financial support, program evaluation remains extremely challenging [50][51]. Causes for the limitations and gaps include: the complexity of the ecosystem, poor agreement on the "right" outputs and metrics and lack of available data, the quality of the data and time-series data sets [52].

While many studies have investigated technology transfer at the micro level [53], these single-actors such as a university technology transfer office (TTO), research labs or companies have different missions and organizational structures. "Collaborative Research Centers are heterogeneous in nature varying widely in missions often including creation of fundamental knowledge commercialization of technologies, education of next generation of researchers and promotion of economic development" [15 p1].

Studies at the micro level only represent a partial stakeholder view and primarily use traditional metrics for evaluation. Econometric studies are plentiful at the macro level. However, the aggregated data isn't useful to compare CRCs. So, the disparity in the unit of analysis is one reason why comparing GUI CRCs is challenging [54]. Researchers have identified the lack of research for comparing CRCs as the "missing middle" [55]. Figure 2 shows how CRCs are boundary spanning organizations positioned in the middle level of performance evaluation problems.

Basically, "improved methods are needed for program evaluation" [[56] p 11] because a GUI CRC is a complex ecosystem [57]; not a "trivial machine, with a defined input-output ratio" [14]. Table 1 provides a wealth of evidence to support the three leading gaps: ecosystem complexity, lack of data, and inadequacy of traditional indicators.

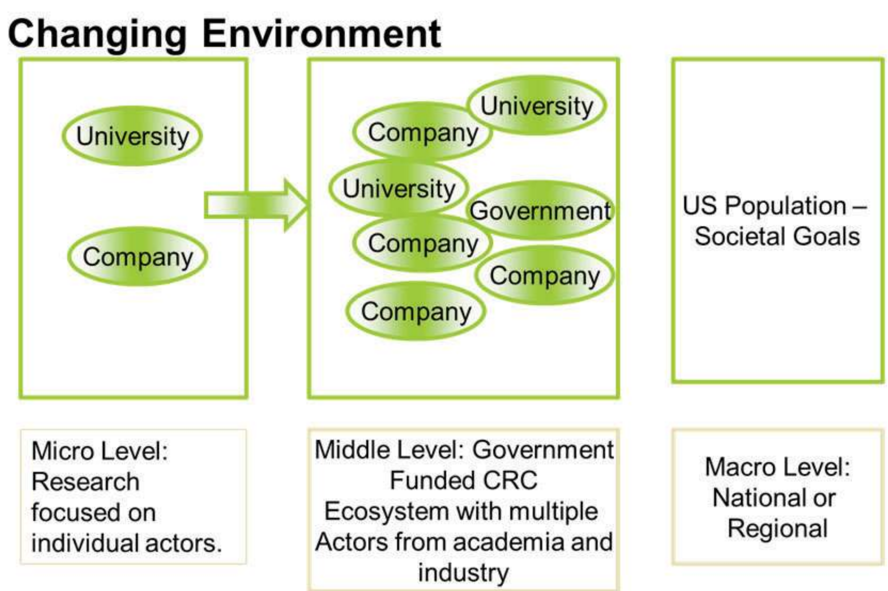

Figure 2: CRCs are ecosystems

TABLE 1: EXAMPLE OF PERFORMANCE EVALUATION CHALLENGES FOUND IN LITERATURE

Reference	Findings	Theme
Boardman and Gray, 2010	"CRCs are inherently complex and therefore a challenging phenomenon to understand". [[6] p 5]	Complexity
Roessner,et. al, 2010	Lack of a "standardized performance criteria" and "exclusive reliance on quantifiable data" provides misleading results. [58]	Traditional indicators inadequate
Schmoch et al., 2010	"scientific performance should not be measured by a one-dimensional metric such a publication, since it is a multi-dimensional phenomenon." [[59] p2]	Traditional indicators inadequate
Palomares-Montero and Garcia-Aracil, 2011	"It is difficult to obtain valid and reliable data and the results of evaluation processes depend on the quality of the information available. There is a lack of disaggregated data to enable comparison among disciplines, and data often are not sufficiently firm, resulting in indicators that provide inaccurate results". [[60] p353]	Lack of available data, Traditional indicators inadequate
Penfield et. al., 2014	"These 'traditional' bibliometrics techniques can be regarded as giving only a partial picture of full impact with no link to causality. [61]	Traditional indicators inadequate
Abbasi et al. 2014	"Collecting network data has its own limitations" and lack of other types of data prevents performance comparisons. [[62] p72]	Lack of available data

While traditional outputs of university research projects such as publications and patents are easily quantified with bibliometrics data, "exclusive reliance on quantifiable data" causes misleading results [58] by painting a partial picture [61]. However, "identifying a set of metrics to evaluate the performance of a university-based ecosystem was [remains] a considerable challenge" [[63] 4]. So, the "STI [science and technology] indicators that were important last century may no longer be so relevant today and indeed may even be positively misleading" [[64] p588]. Or worse, are simply the "wrong" metrics [14].

Therefore this paper adds value to the stream of literature by developing a model that measures the degree in which different science and engineering centers meet a program's mission specifications using a balanced set of performance indicators.

III. METHODOLOGY

The objective of the model is to determine the effectiveness in which an IUCRC meets the NSF program's mission. Organizational effectiveness is a construct rather than a concept [65]. Concepts are abstractions defined and measured by characteristics. Higher-level abstractions are often difficult to characterize and measure requiring expert judgment and construction of different concepts. In the organizational theory literature, Steers [66], and other researchers [67] suggest the first step in clarifying the construct is to identify all of the elements in the domain of organizational effectiveness and then determine how they are related.

The hierarchical decision model (HDM) is a flexible decision support tool that can be used to quantify expert judgment. A key aspect of this method is that the problem can be broken into a hierarchical structure [68], where experts can judge a series of elements in pairwise comparisons. Cleeland and Kocaoglu introduced a mission-objectives-goals-strategies-activities (MOGSA) framework [69] that is well suited for this performance evaluation problem. Elements identified to measure the effectiveness in which an IUCRC meets the NSF program's mission include objectives, goals and measureable outputs. Figure 3 shows how the new model follows the first three levels in the MOGSA framework and replaces the 4th level with measureable outputs.

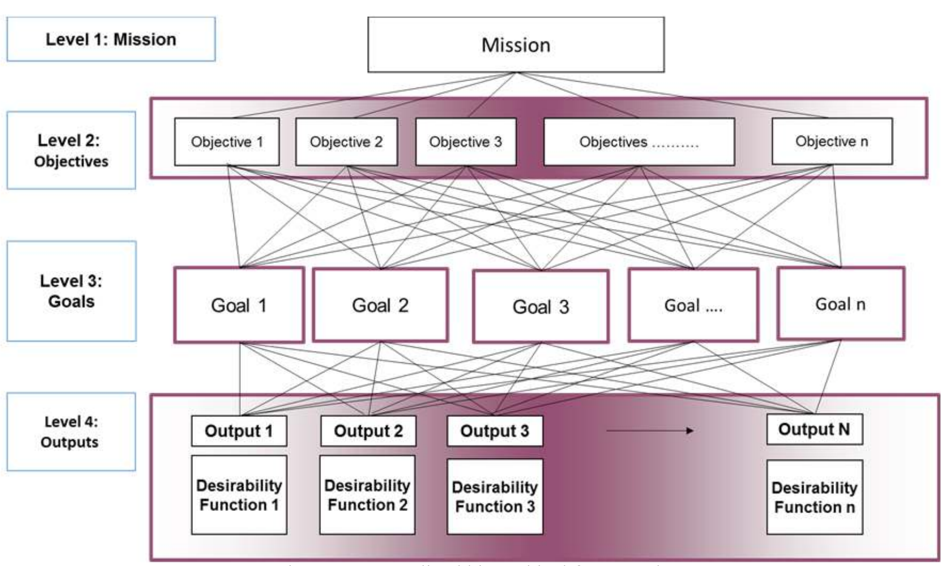

Figure 3: Generalized hierarchical framework

TABLE 2: CLARIFICATION OF NSF IUCRC PROGRAM OBJECTIVES

NSF IUCRC Objective	Research Based Evidence
1	In order for research to be relevant, it must address opportunities and problems faced by a constituent community [70]. Federally supported cooperative research centers are mandated to be problem focused rather than disciplined focused [71]. Research outputs relevant to IAB members include new knowledge and new commercialization events [72].
2	"The distinction between a student taking a traditional course and one doing research is that the former is a receptacle of knowledge and the latter is the creator of knowledge" [73]. Industry support and student research is required [74].
3	Technology transfer is a boundary spanning activity [100]. Technology transfer can be directly transferred in the form of commercialization events or indirectly transferred through human knowledge [75].

The NSF's IUCRC program was developed to transfer "know-how" in the form of organizational structure and best management practices from the NSF to a director and managing research staff at an established IUCRC. Through research projects and other IUCRC activities, technical knowledge and technology is transferred from researchers to industry members and their companies. The NSF specifies the mission of the IUCRC program through three objectives: "

1) To pursue fundamental engineering and scientific research having industrial relevance.
2) To produce graduates who have a broad, industrially oriented perspective in their research and practice.
3) To accelerate and promote the transfer of knowledge and technology between university and industry [[46] pg 23]."

Table 2 describes the objectives so they can be further characterized by goals and measureable outputs.

The first two levels of a multi-dimensional decision model are beginning to emerge. At the top is the objective of the model. The second level comprises the three objectives that specify the mission of the IUCRC program. The next step is to examine the goals and measureable outputs relative to each of the three objectives.

The objective of the model is to evaluate the effectiveness in which a science or engineering research center meets the NSF's specified mission for the IUCRC program.

Objective 1: To pursue fundamental engineering and scientific research having industrial relevance.

Federally supported cooperative research centers are mandated to be problem focused rather than disciplined focused [71]. This means that research projects are funded to either solve a problem or create an opportunity for industry. Perspective of the three primary stakeholders is important to consider. The university is traditionally focused on basic research in science or engineering disciplines and most industry advisory board (IAB) members are looking for invention disclosures that result in breakthrough technologies. "A technological breakthrough or advance may include: significant process improvements, new processes or techniques, and new or improved products or services that resulted either directly from, or was indirectly stimulated by the center's research program" [76].

Therefore, goals that further characterize the first objective include breakthrough technologies and stakeholder and member satisfaction [77].

Objective 2: To produce graduates who have a broad, industrially oriented perspective in their research and practice.

Graduates are produced through acquisition and development. Literature is concerned about the knowledge, experience [78] and diversity [79]. Ultimately, the process of producing graduates who have a broad, industrially oriented perspective falls under the center director because they are responsible for acquiring industry members [46] and high-caliber researchers. For example, respected faculty and a high-ranking university can attract students allowing the university to produce more and higher skilled graduates. Funding, interesting research projects and support help attract students to programs.

Objective 3: To accelerate and promote the transfer of knowledge and technology between university and industry

The facilitation of technology transfer involves activities that turn research results into commercial applications. Link's model shows how successful commercialization of a technology could take a direct path speeding the transfer of technology or an indirect path where knowledge transfers first [17]. For example, if the commercialization is delayed or even canceled publications, patents, and other means of human knowledge may be carried forward for technology transfer outside of the IUCRC. Figure 5 adapts Link's model to an IUCRC research project.

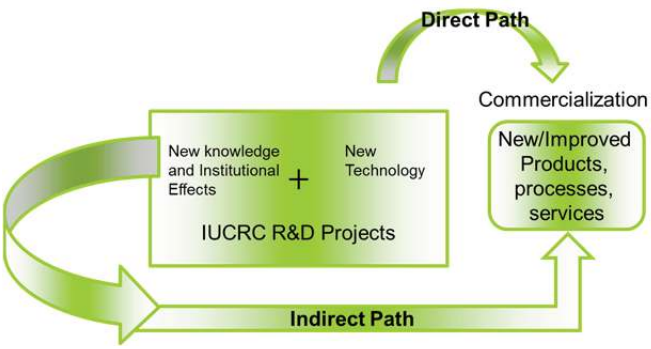

Figure 4: Technology Transfer paths [13]

Measureable outputs

In order to measure and characterize the goals, outputs must be identified with established metrics.

Rivers cites a key reasons that organizations join IUCRCs is exposure to **breakthrough technologies** as a "source of new ideas and perspectives" [[80] p 178]. Literature emphasizes that experts must be engaged to identify breakthrough technologies [41] because they are hard to measure and define [81]. NSF evaluators also found most informants of breakthrough technologies "who had benefited were unwilling or unable to provide economic impact estimates for R&D and commercialization outcomes" [[8] p vii].

Recognizing this, the NSF evaluators have developed a structured template and consistently used it to gather and publish peer recommended breakthrough technology information in the NSF Compendium. They've found "that nearly half of the breakthrough involved new knowledge (32%) or the discovery of a new research method or technology (15%) [[72] p 13]." Because "breakthrough technologies are rarely plug-compatible with existing systems of use" [82], they take time, money and additional research to turn into commercial value. So, the effort by the NSF evaluator team to collect subjective data about breakthrough technologies make them easier to count; but, the impact is still difficult to assess. The outputs relative to breakthrough technologies can be defined as new products, new methods or new processes discovered by researchers or the knowledge about them documented in papers published by academic journals.

Figure 6 provides a framework to discuss measurable outputs relative to the objectives and goals.

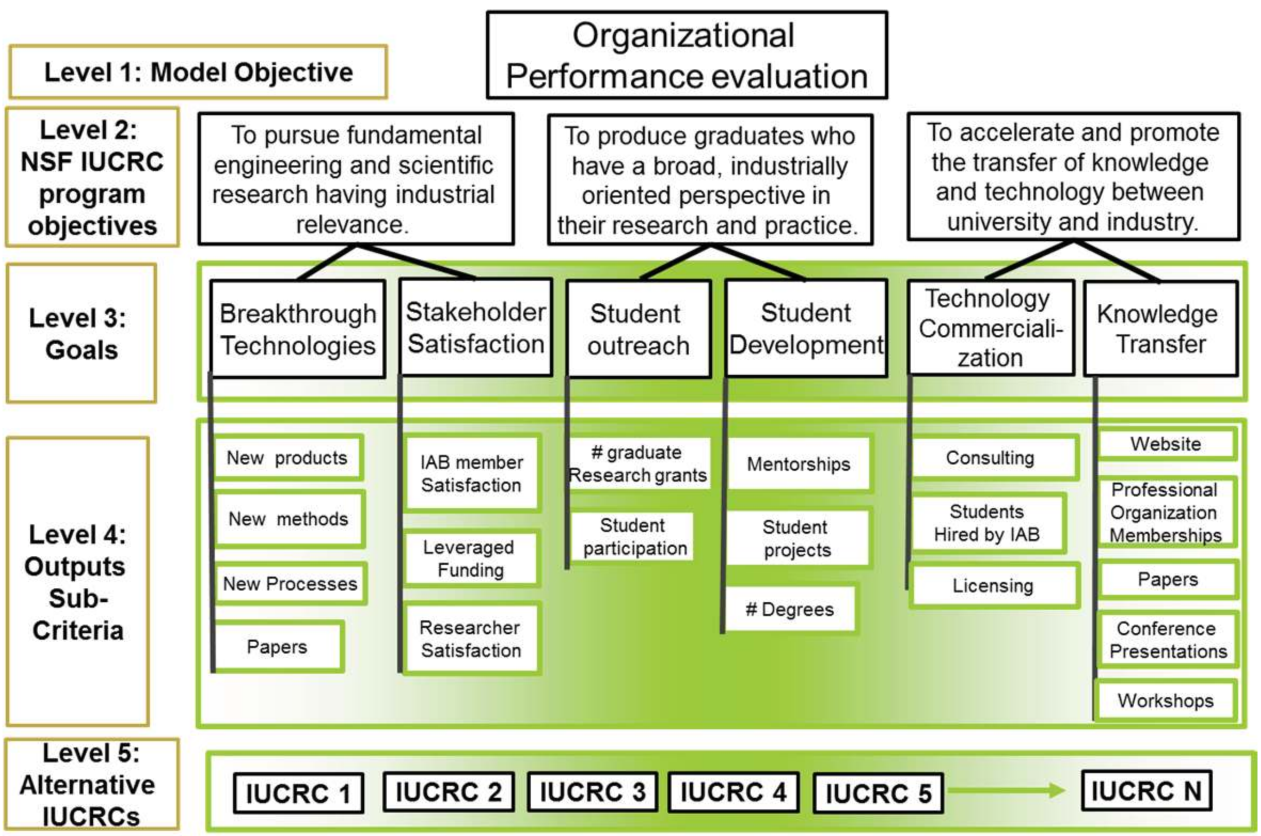

Figure 5: A model for IUCRC organizational effectiveness

While it is common for goals to have multiple outputs, each must have an associated metric. Metrics are specific quantifiable values that are based on desired output levels. They should be specific, measurable, attainable, realistic and timely (SMART). For example, a mathematical formula that calculates a value when populated by objective data is an ideal way to specify a value. Specifying a metric can be challenging, especially when qualitative data must be used to populate the metric.

For example, new products can be measured by the number of technology discoveries resulting in new products [83]. A metric for new products can be derived through a formula that quantifies a value as depicted in equation 1. Furthermore, it can be normalized by considering the number of university partners over a time period as shown in equation 2.

Equation 1: New product metric

New products = # technology discoveries attributed to new products.

Equation 2: Normalized New product metric

New products = # technology discoveries attributed to new products/5 year period/# University partners.

Papers published in scientific journals and conference proceedings are traditionally recognized outputs that transfer basic research to industry. Rivers found that 6% of the IAB members perceived a need to support basic research in their field [84].

There are three primary stakeholder groups that contribute to the objective of pursuing fundamental, industry-relevant engineering and scientific research. The NSF, as program sponsor, is the primary stakeholder. Performance appraisal is important to the practice of CRC management to understand and maximize the impact of their research findings. Measures for organizational financial health [85] are a common indicator of effectiveness. **Leveraged funding** [8] is one measure of NSF satisfaction because it helps to understand the organization's "ability to capitalize" [15] the NSF's funding contribution [61].

A total of twenty (20) output elements were identified through the literature review. Table 4 defines the metric, possible data source and desirability range for each of the defined outputs.

Membership renewal of the industrial advisory board (IAB) members is important because without members there really is no industry cooperative research center. Researchers have correlated In a regression study investigating **IAB member satisfaction**, researchers found "relevance not general quality, appears to be paramount" [[86] p253] for membership renewal decisions. This implies, if an IAB member perceives the research projects are relevant, they are more likely to pay their dues and retain their membership status. So, IAB member satisfaction can be measured when an existing member renews their membership [87].

TABLE 3: GOALS CHARACTERIZED BY MEASURABLE OUTPUTS

Goals	Outputs	Metric	Data Source	Value Range
Breakthrough Technologies	New products	# /5 year/#university partners.	Compendium	[0 , >3]
	New methods		Compendium	[0 , >5]
	New Processes		Compendium	[0 , >5]
	Papers	# journal publications/5 yr/#partners	Elsevier	
Stakeholder Satisfaction	IAB member satisfaction	% of membership renewals averaged over a 4 year period. (Years 2 – 5)	CD Report	[0%, 100%]
	Leveraged Funding	$ other new sources: $ NSF /5 years (excludes licensing revenue)	PO Report/ CD Report	[0, 10]
	Researcher satisfaction	Likert scale satisfaction	PO Report	[1, 5]
Student Outreach	Graduate research grants	# of grants for theses and dissertations	TBD (NSF)	
	Student participation	# of student members/5 years	CD Report	
Student Development	Student projects	# student publications(presentations)/5 year	CD Report	[<2, >5]
	Mentorships	Median Ratio researcher: graduates/ 5 years	CD Report	[0 , 1]
	# Degrees	# (BS + MS + PhD)/5	CD Report	[0 , > 5]
Technology Commerciali-zation	Licensing	# new licenses/5 years	PO Report	[0 , >3]
	Students Hired by IAB member	% of participating graduates hired by IAB member firms averaged over 5 years.	CD Report	[0 , 100%]
	Consulting	# Consulting contracts for researchers to IAB member companies/5 years	TBD (NSF)	
Knowledge Transfer	Website	Quality of information dissemination on website	Website	[0,>5]
	Prof Org Memberships	# of professional memberships held by IAB members/5 years	CD Report	[0, >8]
	Papers	# co-publications (researcher and industry member)/5 years	CD Report	
	Conf Presentations	# conference presentations/5 years	CD Report	[0 , >12]
	Workshops	# seminars and workshops held	CD Report	[0 , >12]

TABLE 4: GOALS AND OUTPUTS RELATIVE TO OBJECTIVE 3 [88]

Level 3 goals CRC model	Tran's level 3 goals
Knowledge Transfer	G1: Information Dissemination (Websites, publications, conferences, workshops, etc.) G2: Professional Networking (Number and ratio of researchers holding professional memberships)
Technology Commercialization	G4: Personnel Movement (Student internships, jobs, dual-position faculty, researcher exchange programs and researcher hires) G5: Consulting (Researchers consulting with industrial company) G6: Transfer of Intellectual Property Right (Licensing)

Preeminent faculty who have a track record of winning grants and other academic and professional awards are not only responsible for creating many of the new technologies but are also instrumental in attracting bright students. The NSF compiles descriptive statistics obtained from surveys conducted of faculty and industry members. A faculty questionnaire presents 13 items to researchers asking about their satisfaction of the research, their perceived benefits and personal impact, their level of intention and commitment and satisfaction of the center's administrative operations. The process outcomes report analyzes the qualitative information to measure the level of **researcher satisfaction** with a center.

An IUCRC requires graduate involvement [46]. Funding and scholarships provide graduate students opportunities to complete research towards a thesis or dissertation making programs more attractive [74].**Student grants** and **student participation** are outputs of student outreach.

Once students become associated with an IUCRC, they are further developed by conducting research on projects, through mentoring with research staff and taking classes in degree earning programs. **Student research projects** can be measured by the number of student publications and conference presentations. Students also develop a broad range of skills through effective **mentorship** programs with both faculty and IAB members. So, taking classes and conducting research are ways in which students develop. Earning **degrees** is a measure of that effort.

The transfer of knowledge and technology is another construct in itself. The complexity of the concepts have been studied extensively by many researchers. Therefore, an approach that extends existing research is logical and warranted. Tran provides the basis for this extension in his evaluation of university knowledge and technology transfer effectiveness (UKTT). One of his objectives to "advance society's knowledge" has similarities with the goal supporting objective three: to accelerate and promote the transfer of knowledge between university and industry. Here, we can see that industry could be considered a sub-set to society. Technology commercialization is the degree that research outputs follow a direct transfer path for intellectual property.

Tran's research synthesized UKTT mechanisms into nine (9) groups. Five of these goals are mapped to either the technology commercialization or knowledge transfer goal in this model as denoted in table 5.

The CRC literature agrees with these knowledge transfer goals by emphasizing the importance of relational and intellectual capital [5]. Relational capital increases as the relationships developed through the social interactions facilitates knowledge creation [89], knowledge transfer [90], and better research outcomes [62][91][92].

Co-authored papers, conference attendance, workshops and informal meetings, peer recognition awards are all examples of relational capital types of outputs. Workshops [93] and informal meetings [94] have been found by other researchers to provide the greatest form of knowledge transfer at the co-opetive level because repeated positive interactions increase trust [47]. One common metric of trust is repeated co-authorships [95][96].

For example, when cooperative research is published by co-authors in an IUCRC, their work can be threaded together forming a large network. "Such an interconnected chain of relationships constitutes a social network in which valuable resources are shared in the forms of information, understanding, and knowledge through the conduct of social interactions" [[95] p1516].

Mapping the goals in Tran's model to the goal of technology commercialization in this model is supported by the CRC literature review. While licensing is a popular and quantifiable measure, researchers also stress the importance that IAB members place on "access to students trained in industrial relevant research" [[51] p 139]. When students are hired into industry, knowledge transfers from the higher education institution to the company.

IV. CONTRIBUTIONS AND FURTHER RESEARCH

The first contribution is the clarification of concepts and construct of CRC performance evaluation. The HDM developed provides clarification of each of the concepts before linking them together to clarify the construct. This method could alleviate some of the complexity between the elements that are inherent in the balanced scorecard method; however, the balanced scorecard could be a novel way to balance the stakeholder value perspectives.

This model is similar to Geisler's Process-Outcomes model [20] and Phan's HDM [83] model in that experts are used to establish indicators and weights for an evaluation score. This model is different because it organizes indicators around the IUCRC mission specified by objectives. Ruegg's CPRS scoring model [56] and Tran's HDM model [88] also use a mission-driven organizational approach. However, another difference in this research is the level of the unit of analysis. Geisler's work is focused at the macro level comparing agencies or national programs. Phan and Tran are focused at the micro level comparing individual actors. While Ruegg's work is focused on comparing the value of a portfolio of projects, this research is focused on comparing performance of NSF science and engineering research centers within the same program model.

These studies are relevant and significant in that they establish a precedence and value for this study. The methodology used by Phan and Tran provide a method for the selection and establishment of weighted indicators that are noted as limitations in some of the other studies. The next step for this research is to validate the content with experts and test the model by further developing weights and desirability curves.

In a complex ecosystem, stakeholders may provide conflicting judgment about the relative usefulness for each of the metrics. Kocaoglu provides some insight into this concept in the form of desirability values explaining that these values represent how good or desirable the output is to the decision maker. In strategic decision making, decisions are often based upon the "usefulness" of the output. Therefore, expert panels are required to determine the usefulness of different output values that would be used to create desirability functions for each output metric.

Developing desirability curves for each of the metrics enables a score to be developed after the metrics are populated with data. Experts responsible for judging the outputs and metrics may aid in the development of desirability curves for each of the metrics. Or, a specific expert panel can be developed to provide this data to judge how desirable each value is along the scale. In other words, experts can provide their opinion on the desired values in the ranges established for each of the metrics. Normalizing these values by using desirability curves allows scores to be calculated for comparative purposes.

While this paper presents a model, it does not collect the expert data to establish the weights of the elements and determine the desired output values required to score an IUCRC. Application can be demonstrated by populating the metrics with IUCRC data.

For example, IUCRC evaluators examining centers for round two funding may find this tool helpful in their funding assessment. Public policy has required codification for quantified evaluation of programs. Use of this tool would further support adherence to this regulation.

V. CONCLUSION

This paper presents a new hierarchical model to measure the effectiveness of an IUCRC at achieving the NSF's mission for the program. While there are many significant and important studies on science and technology center effectiveness; they were limited by the complexity of the eco-system environment, confusion regarding the "right" indicators and a lack of data. By approaching this middle-level ecosystem problem from a holistic picture, different NSF IUCRCs can be compared to evaluate the effectiveness in which achieve the NSF's mission specified objectives are achieved. Therefore, this study makes strides to fill the gap of a missing evaluation tool. Furthermore, a balanced set of output indicators has not been developed.

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