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Elizabeth Gibson
Portland State University

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Supporting Sustainable Technology Cluster Development: A Performance Measurement Problem

Elizabeth Gibson
Dept. of Engineering and Technology Management, Portland State University, Portland, OR - USA

Abstract--**Managers require metrics to measure organizational performance. However, metrics used by organizations that support technology cluster development are poorly understood in the literature. The most frequently referenced indicator for cluster development is regional economic and jobs data. These macro level indicators are not sufficient to measure the performance inside the cluster, leaving champions and policy makers to struggle with ad-hoc trial and error experimentation. The difficulty in defining and developing a performance measurement system is addressed. This paper lays the groundwork for improved approaches towards measuring the performance of technology cluster initiatives.**

I. INTRODUCTION

Thinking about best practices for technology cluster development has changed from providing incentives for large, individual firms to relocate towards fostering an environment that helps technology to emerge and develop more organically [1], [2]. Technology clusters have long been accepted as mechanisms to achieve superior economic performance in a region [3]. Porter modernized Marshall's early work that studies industrial clusters [2], by developing a framework for competitive advantage (diamond) where he validated business clusters as a means for sustainable economic growth [1]. Porter defines a cluster as "a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementaries" [[4]pg 254]. Through a wealth of both qualitative [5], [6], [7], [8] and quantitative [9], [10], [11] studies, researchers have validated that nurturing and developing a cluster is a better method for regional economic development than to create one.

Initiatives are developed and led by champions to support and increase the commercialization of new technologies as a region develops into a sustainable technology center. Champions have experimented with many different types of organizational structures as they search for superior competitive advantage. Effective organizations have helped regions develop into nationally recognized technology centers [5], [12], [13]. However, there is a gap in the scientific literature that discusses how to measure the performance of these organizations.

Research Universities and science and industrial parks have been successfully used as organizational structures to transfer technology and support emerging technology cluster development [14], [15]. Typically, they are led by champions from the university sector with a deep industrial network. One early example was the development of the Stanford Industrial Park championed by Frederick Terman [16]. However, government started looking for practical organizational structures [17], [18] that supported local entrepreneurship [13] and knowledge transfer [19] beyond the university sector [20]. Influencial champions inside the cluster have also realized that sustaining the economic performance of the region required leadership outside the university sector [21] and agree that the triple helix of government, university and industry must be working collaboratively to increase knowledge transfer along the value chain [14], [22], [23], [24].

Other researchers criticize the Triple Helix model as inadequate because it does not consider institutions for collaboration and institutions for financing [25]. As the environment shifts towards a knowledge economy, "networks linking public and private, domestic, regional, and global sector research and technological development entities" are a key success factor [[26] pg 421]. In general, modern research finds that effective organizations are structured as a not-fot-profit, socially-networked entity with influential stakeholders from five segments: academia, industry, government, support groups for collaboration, and investor groups [27], [28]. Therefore, one critical role of the support organization is to span the boundaries of actors in these five sectors to foster the transfer of knowledge [21].

Champions from the academic, public and private sectors can contribute to the economic success of their regions by understanding the competitive strengths and challenges of their regions' industrial clusters. While there is extensive research examining cluster economic performance [9], [29], [30], operational performance requires extension of the current research [31], [32]. Research that examines the organizational characteristics, outcome and output expectations from the organization, and develops a way to measure them is a critical next step.

The following paper lays the groundwork for improved approaches to measure the performance of organizations created to support technology transfer. Including this introduction, the paper is organized in 6 sections. Section 2 reviews the academic literature on organizations supporting technology clusters, definitions, concepts and relevance. It summarizes the gaps in the literature and brings it up to date. Section 3 outlines the complexity and problems for developing a performance measurement system for a technology cluster support initiatives. Section 4 presents outputs for different types of structures in the technology cluster ecosystem. Included are the outputs of I/UCRC type structures, 5-pillar type structures and the Oregon signature research centers. Data describing outcomes, outputs, and indicators were obtained from a signature research center through expert interviews and examination of internal reports. Section 5 compares outputs used by the different organizational structures involved in research-based ecosystems, summarizes the discussion laying the groundwork for improved performance measurement approaches and concludes the paper.

II. TECHNOLOGY CENTERS, CHAMPIONS AND SUPPORT ORGANIZATIONS

While the term "technology center" is still gaining definitional consensus in the academic literature, technology centers have been used as structures for knowledge and technology transfer for decades. Unfortunately, it has been used somewhat as an umbrella term in different domains which may add confusion to the definitional debate. In order to clarify a working definition, the literature on technology centers was grouped by domain into: international, national, and regional use of the term.

Internationally, the term has been used to describe institutions such as Entrepreneur Research Centers [29], national research centers in Thailand such as the National Metal and Materials Technology Center (MTEC) [33], knowledge centers in Europe [34], the VCI Technology Center in Germany [35] or Science and Technology centers in India. Internationally, technology centers can also be organizations specifically developed to support a specific technology cluster such as the Sensor Technology Center in Denmark [36].

At the U.S. national level, researchers often use "technology center" to describe a National Science Foundation (NSF) Industry-University Collaborative Research Center (I/UCRC), Engineering Research Center (ERC) [37] or Science and Technology Center (STC) [37].

Researchers concerned about regional economic and technology cluster development will refer to a technology center as either a geographic region known for technology such as "Silicon Valley's role as the dominant technology center" [[38] p 60], and "Austin as an emerging technology center" [[20] p 9]; or, as a specific institution such as the Ben Franklin Technology Center at Lehigh University [39] or the Massachusetts Institute of Technology Center [40]. At times, the literature has used the term "technology center" as a general synonym for an organizational structure such as an incubator [39], a university based research center [41], a technology cluster and a technopolis [42].

> A technology center is a geographic region known for superior expertise in commercialization and development of a particular technology.

A technology cluster can emerge in any region that has economic activity attributed to technology; whether or not the actors are working together to benefit the development of the cluster as a whole [43]. Types of clusters with primarily independent actors are commonly referred to as agglomerations. Many years can pass as the cluster grows organically until a champion emerges to catalyze the creation of a formal support initiative. For example, the Silicon Forest is a recognized technology cluster in Oregon; but, is primarily sustained by Intel and Tektronix who are independent companies in the cluster.

Different organizational structures are used to develop different types of technologies as a cluster develops and matures towards becoming a technology center [44], [28]. While literature shows that I/U structures are instrumental in the emerging phase of technology clusters, basic research sometimes suffers at the expense of commercialization activities [37]. This could be one reason why many of today's technology centers that were initially supported by university research centers, science parks or other organizations are currently being supported by a 5-pillar organizational structures. They simply outgrew them. Porter [9] and other researchers [20], [45], [24], [46] support this idea as they argue to extend beyond the Triple Helix pillars to include actors in other sectors such as institutions for collaboration (IFCs) and institutions for finance (IFFs) [46].

Table 1 shows the current organizational structure of some well known technology centers as the leading support organization expanded beyond the I/U relationship. Several organically developed through a network of champion led support organizations [47] for many years [19] before evolving from an informal organization to a social network structure conducive for knowledge transfer [48]. Currently, the support organizations listed below are all not-for-profit.

TABLE 1: TECHNOLOGY CENTER EXAMPLES OF STRUCTURE AND FOCUS AREA

Technology Center	**Leading Organization**	**Date**	**Type of Structure**	**Technology center focus areas**
Silicon Valley (SV)	SV Leadership group (previously SV manufacturing group)	2005 SVLG	Non-profit advocacy group that replaced Joint Venture Silicon Valley (JVSV) as primary support organization	Technology innovation and entrepreneurship
Austin Texas	Greater Austin Chamber of Commerce	1920's	Non-Profit chamber: 5 pillar representation	Tech manufacturing, clean tech, life sciences, software
Research Triangle	Research Triangle Regional Partnershp (RTRP)	1959 AEDO 2011	Public private partnership (PPP) research park (RTRP) then AEDO Certified	Advanced medical care, cleantech, informatics, defense technologies, pharmaceuticals, nanoscale technologies
San Diego	CONNECT	1985	501c Trade Organization	Advanced defense, life sciences

TABLE 2: ORGANIZATIONS SUPPORTING TECHNOLOGY CENTER DEVELOPMENT

Technology Center	Initial primary research University	I/U Partnership Organization	Triple Helix Organization	5 Pillar Organization
Silicon Valley, CA	Stanford University (1939-1950)	Stanford Industrial (Research) Park (1951)	Joint Venture Silicon Valley (1992)	Silicon Valley Leadership Group (2005)
Austin, TX	University of Texas, Austin (1960-1976)	Innovation, Creativity, and Capital Institute (IC^2)	Greater Chamber of Commerce, Austin	Austin Technology Incubator (ATI)
Research Triangle Park, NC	North Carolina State	Research Triangle Development Council (1956)	Research Triangle Institute (1958)	----------------------
San Diego, CA	University of California, San Diego	CONNECT (1985)	CONNECT Association (2005)	CONNECT Foundation (2005)

Research has found that technology clusters have developed faster and with greater impact through determined regional leadership action [49], [50] and sustainable initiatives [51]. Intentionally constructed organizations such as industrial parks and incubators are generally viewed as effective structures to develop emerging technology clusters; but not for sustainability. They are limited because they originated through policy mechanisms with specifically stated objectives.

Research shows that the organizational structure must grow to include a broad network of champions for the regional technology cluster to develop into a nationally recognized center of excellence [19]. Feld considers that a critical mass of entrepreneurs to provide leadership is often less than twelve and these leaders do not come from the government sector [52]. Other researchers using social network analysis (SNA) research methods "find empirical support for Feld's work" and "that entrepreneurs are leading" the technology clusters [53] p 14. Even the Silicon Valley follows this pattern by expanding beyond a research university, to a research park, to a venture corporation to a non-profit advocacy group with representation from the 5 pillars. Another example is CONNECT Association; re-formed as a 501c organization to support sustainable growth of the San Diego life sciences technology center. Table 2 highlights organizational changes as different technology clusters developed into well-known technology centers.

A strong champion (godfather/godmother) is critical to start a network of influencers who eventually become involved in a 5-pillar type organization. Today many consider Fred Terman to be the godfather of Silicon Valley because he was not only supporting Stanford graduate students (Hewlett and Packard) to commercialize technology in their garage in 1939; but, also continued to champion the commercialization of technology by founding the Stanford Industrial Park [54]. Following current theory that sustainable technology clusters must grow beyond the I/U sectors and initial godfather, the Silicon Valley Leadership Group was formed to support and lead development of the technology center of the Silicon Valley region [55].

The technolopolis of Austin, Texas also follows this pattern. The University of Texas in Austin, Texas, was the nexus to foster emerging technology [20]. A technology cluster began to develop further in the region as Kozmetsky, a strong champion and recognized godfather, stepped forward with the ability to link different segments [54]. Through his formation and leadership of the Creativity, and Capital Institute (IC^2), champions and investors were recruited to form a network of influencers [20]. Today, Austin Technology Incubator supports emerging technologies and the formation of new networks to sustain the technology center. For example, the Austin Wireless Alliance (AWA) was formed as a non-profit organization, with primary stakeholders from business, academic, the community and government sectors to support and develop a wireless technology cluster [27].

Expanding upon a framework, first presented by Gibson and Conceiçao [56], figure 1 shows how champions are the nexus of a 5-pillar socially networked structure. In general, these organizations are structured as not-for-profit, public-private entities [46], led by multiple entrepreneurial, godfather-like influencers who support multiple technology cluster support initiatives [52], [53].

III. PERFORMANCE MEASUREMENT CHALLENGES

With all this complexity, what indicators should be used to measure and compare performance? And, how is superior performance being evaluated today? Through a search of the scientific literature, multiple studies were found that evaluated the performance of technology centers and actors within the centers. Table 2 summarizes the different methodologies being applied to the research area.

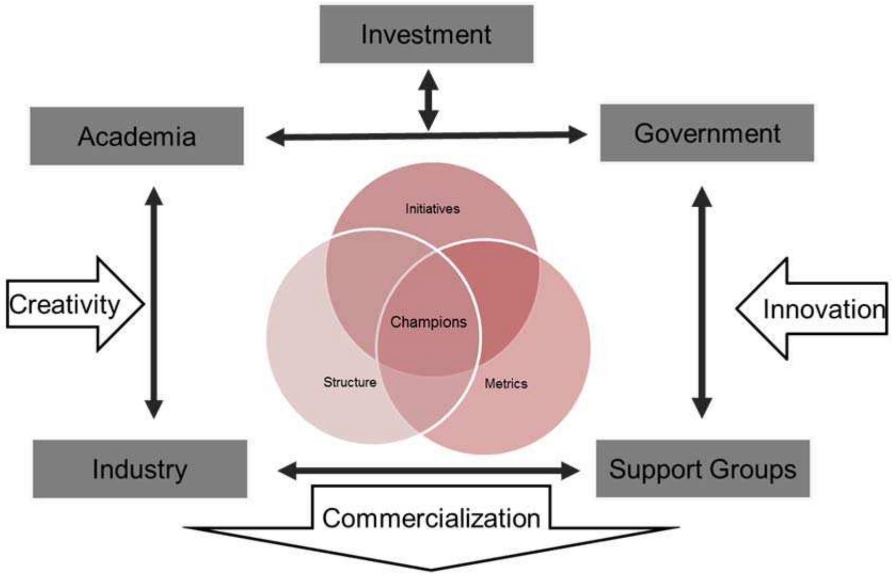

Figure 1: Framework for a 5 pillar organizational structure

TABLE 2: RESEARCH METHODS USED TO MEASURE TECHNOLOGY TRANSFER PERFORMANCE OF DIFFERENT ORGANIZATIONAL STRUCTURES IN TECHNOLOGY CLUSTERS.

Characteristic	Top-down	Bottom-up	Top-down/Bottom-up
Research Question	How Much?	Why and How?	Which One?
Approach	Quantitative	Qualitative	Qualitative Quantification
Principal Data	Secondary Data	Primary Data	Primary and Secondary
Methodology	Statistical modeling [9], [57], [29], [58], [59], [60], [61], SNA [53]	Case Studies [2], [3], [5], [20], [38], [8], [16], [62], Surveys [63]	Multi-Level-Criteria [64], [65], [66]
Industrial	Classification System	Descriptive	Multi-Level-Criteria
Domain	Nationwide, Multi-industry cluster, single industry or single criteria.	Local, single cluster, or single sector	Nationwide, single industry, single actor comparisons
Performance Measures	Employment, Patents, Wages, Output, Sales	Relationships, Institutions	#new products, patents, revenue, publications, start-ups, network interactions

Most of the research literature is focused on the need and importance of technology clusters for economic development [67], [46], [68], [69], [70], [71] and the importance of identifying and developing initiatives [16], [72], [38]. Empirical, top-down studies are often used to compare the performance of regional technology clusters for jobs and economic performance at the macro level. Current studies, typically use input/output models with data found in a central database at the cluster mapping project website: www.clustermapping.us. These are lagging indicators and not helpful to understand the inner dynamics and generation of outputs that contribute to the cluster outcome of jobs and economic activity increase.

So, researchers have studied the performance and innovation in industry [64], of US Academic Research centers [58], and technology commercialization centers [29] at the micro level and cluster output at the macro level. Literature recognizes the "missing middle" [73] between the micro (actor) level and the macro (regional cluster) level placing a call-to-arms for more research to examine the efficiency and impact of activities and functions that make up the cluster [13], [19], [9], [72], [67], [16], [3], [74], network dynamics within the cluster [3] and success factors and performance measures of the organizations that support them [59], [43]. Even Porter [9] has called for more research about the impact of cluster composition on regional economic performance and success factors for sustainability.

Agreeing with researchers who recognize this gap [9], [43], [75], Freeman and Soete conclude "research on STI indicators appears today as challenging as ever" [[76] pg 529]. A recent, extensive, research study, provides testimony from multiple experts who agree that "identifying a set of metrics to evaluate the performance of a university-based ecosystem was a considerable challenge" [[63] 4]. So why is this so challenging?

One reason for this gap may be that a technology cluster is a complex ecosystem [77]; not a "trivial machine, with a defined input-output ratio" [78]. Attempting to "understand the nature of an ecosystem" with a "defined input-output ratio" is inadequate and "may well lead to absurd results" [78]. Other researchers agree that it is better to measure outputs rather than inputs if the "objective is to measure the success of knowledge transfer" because the data is intangible and subjective [79].

Phan only used output indicators in his research about innovation measurements of high-tech semiconductor companies for similar reasons. Through his use of expert panels, he was able to extract their judgment to evaluate output indicators in a hierarchical decision model he developed [64] to compare the innovation of selected companies in the semi-conductor industry. So, a multi-criteria decision model could be of some help. This approach seems to hold some promise for future research.

Next, champions are tasked with creating "economic and technological values by interacting, competing, and collaborating with other actors in innovation processes, which functions as the source of innovative activities for the region" [[80] pg 463]. Values by nature are subjective and difficult to quantify. Through a literature review, objectives and values were classified by the 5-pillars as shown in figure 2. The initiative is sustainable only if it delivers the right value to the right stakeholder.

So, the top-down research does not help because the problem is too subjective to be measured by a linear input-output model. Some researchers have found promising results using output indicators. However, in a recent survey responding experts generally viewed "commonly used research commercialization metrics as unreliable indicators of long-term capability to support or develop a vibrant innovation ecosystem"[[63] p i]. So, many are questioning if the output metrics being used are even the right ones. Several reasons supporting these findings include:

- Performance of the system is based more on knowledge transfer and flow rather than on efficient use of inputs to provide more outputs such as making people work faster.
- In a linear relationship, actors can control the inputs impacting the results of the performance measurement system.
- Success hinges on the emergence of a godfather/godmother [54] to lead and develop a network of influencers. Sustaining an initiative is difficult, requiring expert leadership ability and an adaptive and iterative approach. It takes art, skill and political influence to build a tight network of diverse champions. The network must be flexible enough to integrate multiple godfathers/godmothers.
- The many different stakeholders value different outcomes and objectives.
- Initiatives need to be supported and take time. Authorities must be willing to make long-term commitments [49]. There are considerable time lags that separate productive outputs from the resource inputs further complicating a linear relationship.
- The I/UCRC model has matured to the point of social technology so the output indicators being used to measure these initiatives are being applied to other organizational structures.

The benefits of a performance measurement system are plentiful. Champions leading the organizational initiatives need performance measures to make decisions. It is also important for the multiple stakeholders to understand the organization's value proposition and performance against that proposition to build trust and remain engaged in the network. Policy makers can also benefit from clear performance measures as they use them to make funding allocation, budget and policy decisions. Finally, taxpayers deserve transparency in decisions made that allocates public funding.

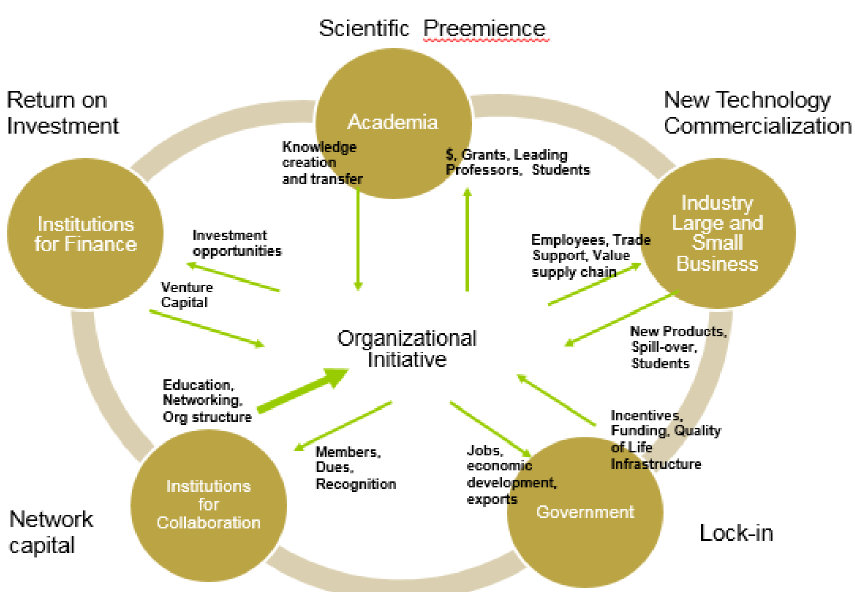

Figure 2: Different economic and technological values by stakeholder pillar

IV. OBJECTIVES AND OUTPUTS

According to a White House memorandum [81], funding agencies, academic leadership, and industry must manage their portfolios in an objective, evidence-based manner to address science and technology priorities of our nation and increase the productivity of our research institutions. As discussed, this is easier said than done. Perhaps the most formal, well-funded and structured program is the one established to evaluate the performance of an NSF I/UCRC [82].

There are three types of outputs of I/UCRCs: research, human and social. Research outputs can be classified into publications, presentations, reports, IP and commercialization events. Human outputs include increasingly skilled researchers and managers as well as a growing number of members. Social capital outputs show bonds, bridges and linkages between actors. Social network maps and other graphical representations of relationships and formations are examples of social capital outputs. I/UCRC metrics identified in the literature were synthesized and displayed in table 4.

The results of a content analysis of the technology center performance literature identified four objectives: scientific preeminence[45] [84] [72], new technology commercialization [85], [86], [61], entrepreneurship [2], [29] [61] [65], [58], [87] and intellectual and social capital [86], [84], [29], [49], [88], [75]. There were many additional concepts adding more complexity to the synthesis including ideas of cooperative competition, human capital increases [61] [16], knowledge and innovation conduits [3], social network structure optimization [60], social capital, efficient, mobile and adaptive social networks [72], increasingly complex interactions [26], and knowledge creation from linkages [75]. Many of these outputs coincide with the values identified in figure 2.

TABLE 4: METRICS USED TO MEASURE I/UCRCS

	Outputs	**Metrics**	**Description**
RESEARCH	Publications	#pubs/PI # pubs/student #Cit/pubs/PI	Quantity of new knowledge Quantity of new knowledge Leverage or use of knowledge
	Reports	$R&D savings $R&D avoidance $NSF/$IAB	 Leveraging of funds
	IP Events	# new processes # new products #IP Events (other) NetPreventValue	New and/or improved processes New or Improved products
HUMAN CAPITAL	Awards/Credentials	# faculty(students) # degrees earned	Awards earned from academic and professional associations, partner universities
	Roles	# job offers/student # promotions #internships/student	I/UCRC related work
	People	# student/PI # IAB members # Researchers	Innovation capacity Director managerial skill/ability
	Projects	# RFPs, Projects	
SOCIAL CAPITAL	**Bonding**	#pubs w/IAB mem # communication events, workshops [83] #Networking events Satisfaction survey	Co-authorship and collaboration within IAB membership information, activity, attendance and networking opportunities. Networking, events connections within group. IAB Satisfaction
	Bridging:	# Spillover #new collaborations Centrality Betweenness	Knowledge transfer Spillover channels Collaboration SNA maps Joint research output produced by members of different organizations
	Linking:	# Spin-outs, start-ups # Start-up funded (not bootstrapped) $ funded ROI	Commercialization events, funded startups. Knowledge spill-over from the I/UCRC to other non-member actors.

The state of Oregon is currently experimenting with different organizational structures to support technology cluster development. After the state of Oregon identified the technology industry as warranting cluster development and support [85], a public-private partnership was formed as the Oregon Innovation Council (Oregon InC). The mission of this organization is to “create innovation into the DNA of how Oregon does business” [89]. As a result, three initiatives were launched over a ten year period and structured as signature research centers (SRCs). The (SRCs) were intentionally created to increase collaboration amongst five of Oregon’s public research universities and industry to foster new partnerships for the purpose of increased technology and knowledge transfer. At the same time, others are exploring a 5-pillar model that includes institutions for collaboration and institutions for finance in a formal organizational structure.

Through interviews with experts and evaluation of internal documentation it was found that the signature research centers are not as concerned with basic research outputs as much as they are with applied research and commercialization outputs. The measures are depicted in table 5. Only the social capital outputs identified by the I/U type structure in the university based ecosystem actually overlap with technology cluster initiatives as found by this case study.

TABLE 5: OREGON SIGNATURE RESEARCH CENTER METRICS

Applied Research Outputs	**Commercialization Outputs**
# companies using lab resources # New companies using lab resources Leverage of research $	# Start-ups in place # Start-ups created $ Raised for follow-on funding Leveraged investment (4:1) Amount of new out-of-state capital

V. CONCLUSION

The technology cluster ecosystem is complex and filled with uncertainty with a large range of initiatives to support different stakeholder needs. Different leadership skills and structures are required as a cluster matures into a nationally recognized technology center. While a technology cluster can organically emerge and develop without organized leadership; economic sustainability is risky because it is dependent on independent actors. These type of clusters are agglomerations of companies working independently rather than a technology center with an ever deepening network of entrepreneurs.

Knowledge creation typically starts with basic research at the university. Transfer of technology has been shown to increase through industry/university collaboration. Different structures such as research parks, incubators, accelerators, signature research centers and shared labs have all been effective at increasing knowledge and technology transfer. Ideally, a godfather will initially emerge from academia or industry with the ability to build a network of other influencers into a leadership organization. Then, the process gets less clear.

Through formally organizing, these leaders must then support a variety of long term entrepreneurial development activities. While there is general consensus that a leadership network is necessary, tools and approaches are not sufficient to study the performance of these initiatives. Implementing a new initiative can be risky and expensive. The outputs, indicators and approaches to measure the performance of these initiatives are missing in the literature.

The NSF’s I/UCRC has demonstrated a repeatable model for increasing research and technology transfer to industry members. Evaluators have used outputs to evaluate the performance of different centers. However, researchers and NSF program evaluators have identified gaps to measure social network outputs. These types of outputs were common with the types of outputs identified for technology cluster initiative outputs. Because the I/UCRC structure only comprises a subset of the technology cluster ecosystem and the similar outputs are poorly understood, it makes sense there is a “missing middle”. Therefore, it is important to understand what types of outcomes, outputs and indicators to measure them are generated by technology center leadership networks.

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