Int. J. Engng Ed. Vol. 26, No. 1, pp. 169–177, 2010
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Creating Links from Customers to Technology*

R. SCOTT EVANS[1] and STEVEN P. NICHOLS[2]
[1] *Pretium Consulting, 2801 Post Oak Blvd, Suite 180, Houston, TX 77056, USA.*
[2] *Department of Mechanical Engineering, Cockrell School of Engineering, University of Texas, 1 University Station C2200, Austin, TX 78712, USA. E-mail: s.nichols@mail.utexas.edu*

This paper further develops the Technology Innovation Mapping (TIM) tool introduced in a previous paper. TIM assists activities in technology commercialization by allowing the technology/product development team to better understand the link to customer needs, the important elements of their intellectual property relative to customer interests, and the course of action necessary to improve the likelihood of successful technology commercialization. Use of the tool requires that the team describe and understand specific benefits and unique elements of the technology relative to a defined application. The tool facilitates a clear focus on specific customer needs. The paper provides an introduction to the TIM method, defines key terms used in the analysis, and provides a specific example of analysis.

Keywords: technology commercialization; innovation; function mapping

1. INTRODUCTION

EVANS AND NICHOLS described the Technology Innovation Mapping (TIM) tool, which divides the process delineating value added links between emerging technologies and potential customer needs into a series of steps [1]. They introduced elements of the tool that support what is now regarded as the first step of technology innovation, characterizing the technology. "Characterizing the technology" refers to building a clear understanding of the key benefits and unique technical features with respect to a defined application or related set of applications. The benefits and features are the elements of the technology that serve as connection points or nodes for the creation of links to customer demands.

This paper focuses on clearly linking technology features to specific customer needs, or more importantly the set of customer needs that characterize customer buying decisions. This step of the TIM tool examines customers and the value chain that delivers a product to the customer. By including the concept of a value chain, a broader definition of "customer" emerges that includes not just who uses and who pays, but also those who benefit from a new technology. It serves to illustrate how the concept of a customer can be individuals or could be several different organizations that together establish the complete concept of a customer. It also shows how the value chain helps identify nodes that serve as end points for links connecting the technology to customer demands. Several other steps of the process are covered in other papers. This paper emphasizes three key points. First, it highlights the customer as the driver of technology commercialization. Second, it illustrates how the TIM tool supports the technology innovation process. Finally, the importance of the value chain surrounding a potential customer is illustrated. The purpose of the paper is to provide an overview of the TIM tool step that establishes customer demands. From this overview several conclusions are drawn about the tool and the technology commercialization process more generally.

Table 1 provides the key terms to be used in this paper.

The TIM tool takes advantage of function maps. Function maps are diagrams that illustrate important functions and their relationships. Function maps have been used in a variety of applications and have been developed in different forms. Examples of function map applications include brain function [2], business strategy development [3], viruses [4], manufactured products [5], and even ideas [6]. In the TIM tool two types of functions and two relationships are used to form a function map, as illustrated in Fig. 1. Note that Function A produces or creates Function B as indicated by the direction of the arrows. It is often the case that a function can produce or be produced by multiple functions. The line tipped with a circle connecting Function C to Function D indicates that Function C counteracts or impedes Function D. Finally Function E produces both a useful and a harmful function.

The example that frames this discussion is the application of the TIM tool to a technology from university research laboratories: specifically a concrete testing technology. The example illustrates how to use the TIM tool to define customer

* Accepted 28 November 2009.

Table 1. Key terms for describing the TIM tool

Benefit—A function describing the overarching purpose of a technology. A benefit is a function that could be valuable to a potential customer. Technologies often have several potential benefits and the description of these benefits are often related to a certain set of applications.
Technology Elements—Technology elements or unique elements are a set of functions that define what is unique about a particular technology. For a software technology, the technology elements might include algorithms, data or calculations, but not the computer running the software.
Harmful Function—A function that is defined to be value negative. Costs, production times and failure mode risks are examples of harmful functions.
Useful Function—A function that is defined to be value positive.
Produces—A function can positively influence or produce another.
Counteracts—A function can negatively influence or counteract another.
Potential Customer—A potential user, purchaser or benefactor of a product based on a chosen technology.
Value Chain—The network of value-creating activities that would be required to deliver a future product to a potential customer.
Product—A fabricated object or organized service that is more valuable to a customer than their money.

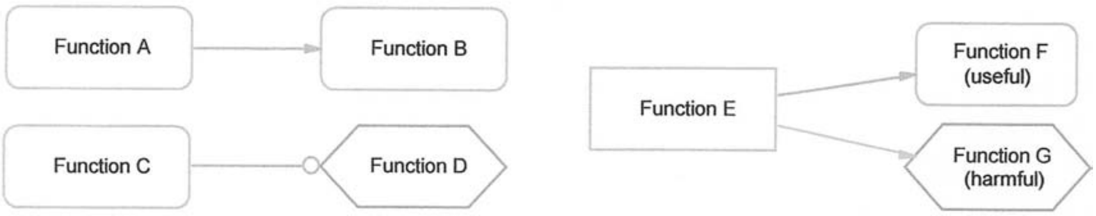

Fig. 1. Language of function maps.

demands and an appropriate value chain. First, the tool facilitates understanding of the value chain surrounding chosen potential customers and the demands that stem from that value chain. Then, links can be created from those demands to the technology. The links then provide insight about opportunities related to the match between the technology and the chosen customers.

2. CHARACTERIZING CONCRETE RHEOMETER TECHNOLOGY

When concrete is delivered to a construction site it is tested to verify that it has the required properties. Small and large contractors currently use a "slump" test to verify the "workability" of wet concrete. Workability, as measured by the slump test, has been correlated to installation and cured concrete properties. It is not a direct measure of specific physical properties such as water content or viscosity. The slump test is specified by the ASTM C143 specification within the United States [7]. To perform the slump test a cone-shaped scoop is filled with a sample of the concrete and inverted on a flat surface. The scoop is then removed leaving a cone of wet concrete. The distance the apex of the concrete cone falls from its full height is the slump which must be within certain limits. Often, this test must be repeated several times to verify its accuracy. The contractor shown in Fig. 2 is measuring the distance the concrete cone has slumped from its full height. The cone used to perform the test is inverted to the left of the concrete being measured in that Figure.

A portable concrete rheometer technology was developed in 2004 at The University of Texas at Austin by Eric Koehler, a Ph.D. student in civil engineering. It is a device that measures viscosity and related physical properties of wet concrete which are combined to indicate ease of installation and cured concrete properties. The testing device includes a portable drill, a specially designed, instrumented impeller bit and software to perform mathematical analysis. The torque is measured while the bit is rotated at various speeds within wet concrete. The torque and speed data are then used to calculate an accurate reading of a variety of properties for the concrete mixture. Dr Koehler's technology was examined by a team of graduate students (law students Nima Aghili and Tim Pasken, business graduate student Nick Bhavsar and engineering graduate students Ryan Oliver and Atif Qureshi) for the Enterprise of Technology

Fig. 2. Contractor performing ASTM C143 slump test.

Course in 2005 [8]. They performed research into the concrete market, but did not use the TIM tool during their work. Their market research is used to populate the TIM tool for this paper and their experience serves as a baseline comparison for the tool.

One way to begin building a function map of a technology is with the benefits or functions that define the purpose of the technology. The benefits of the concrete rheometer technology are listed in Boxes B1, B2 and B3 at the top of Fig. 3. The only benefit described initially by the team was "Provide universal analysis of concrete rheology". This function may be found in Box B3. Maps can be updated easily with new information. If this map were used by the student team, then it would have evolved as their understanding about the technology and its potential applications changed. Later in the semester they included the speed, accuracy, and repeatability of the technology as valuable functions (see Box B2). They also added another function during their research as Box B1. Box B1 indicates that the rheometer test is based on physical properties and is uninfluenced by properties of the concrete not related to installation and final properties. The importance of this function is discussed below. For each of these benefits the functions that produce them can be identified. Functions and subfunctions (down to the technology elements) are identified by defining how each function is produced. The information (Boxes B2 and B3) must be displayed (see Box 11). A portable computer screen (Box 10) and calculating the rheology (Box 9) define how the information is displayed. The input of torque and speed data (Box 8), custom software (Box T3) and the portable computer produce the function of calculating the rheology (Box 9). The required torque and speed measurements (Box 7) are produced by the functions associated with a drill, the special bit and instrumentation (Box 2, 3, 4, 5, and T1) and the appropriate speed settings for performing the test (Box 6). One possible development of the technology would be to integrate the testing functions into a single unit (Box 1). With some careful organization of the map, the technology elements (Boxes T1, T2, T3, and T4) can be placed at the bottom of the map. These elements are new, unique to the technology and were created in the laboratory. Other functions such as those provided by drills or speed controllers are not original to the technology. That said it is important to mention that bringing existing technical elements together in a new way does constitute original intellectual property.

The chains of functions connecting technology elements to benefits form the core logic paths. Those logic paths can be addressed by asking two questions; how and why. All of the arrows leading in to a particular function should define how that function is produced. The arrows leading out of a particular function define why that function is included in the diagram. After forming the core logic paths two steps are important. First any auxiliary harmful or useful functions stemming from each function in the core logic path can be identified and added. Second, any interconnections (both positive and negative) between the functions can also be added. Intermittent auxiliary functions or interconnections are often important. Research about a technology being mapped and competing technologies is often necessary to identify all of the benefits and the network that completely captures the technology. The map in Fig. 3 could include several harmful functions as well. Moving parts produce low reliability. The same effect could be associated with the portable computer, especially at a construction site. Overall this rheology test is more complex to perform than the slump test. These harmful functions have been deliberately removed from Fig. 3 for clarity. The function map of the technology seems to indicate that there is an opportunity for bringing the technology to the concrete market. It is a superior technology.

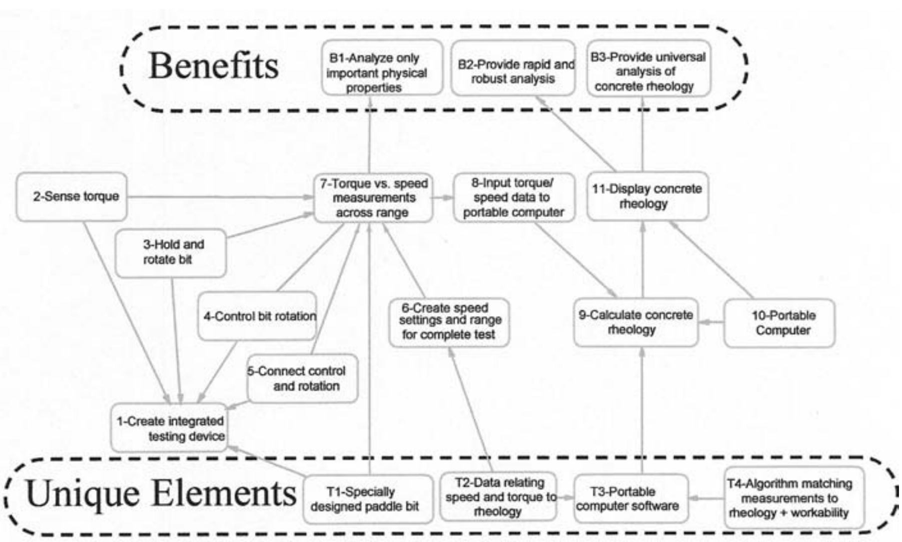

Fig. 3. Function map of concrete rheometer technology.

It is faster than the slump test, provides more accurate and more comprehensive information and is more reliable. Further, it is a test that is administered at nearly every concrete job across the country. There are many potential customers.

It can also be valuable to begin with the technology elements and work toward the benefits. In that way, technology elements help clarify what the benefits of the technology are. The benefits are defined in terms that can be connected to potential customers. They represent the possible product benefits to customers. More importantly for the present discussion, they represent promising connection points for defining links to the demands of potential customers. We could argue that the benefit is "Calculate concrete rheology" (Box 9). From a strictly technical standpoint, that is absolutely correct. However, for the sake of technology innovation two critical features in clarifying the technology are missing. First, the rheology information must be provided to some customer. This is why Box 11 and B3 are included in the map. Second, innovation is driven by customer perceived value, hence the inclusion of Box B1 and B2.

Customer demands represent things that are valued and should connect with the benefits defined for the technology. Identifying the benefits and technology elements are the purpose of characterizing the technology. Addressing customer demands requires, among other things, development of the technology, development of any necessary complementary technology and creating a manufacturing capability. The technology elements are starting points for that development. They help to establish the current status of the technology. They also indicate features of the technology that might be valuable intellectual property. Like all maps within the TIM tool a technology map evolves along with the changing understanding. It can also evolve with further development of the technology. This capability is critical for promoting the iterative nature of the technology innovation process.

3. IDENTIFYING CUSTOMER DEMANDS (FINDING THOSE WHO REALLY CARE)

Engineering design methods serve to delay synthesis activity until after the problem is clearly understood [e.g. see 5 and 9]. Similarly, the TIM tool delays creating links between the technology and potential customers until after the technology is clarified through the creation of a function map. The steps of the TIM tool that support finding and evaluating these potential customers are described in other papers. Since the concrete rheometer technology was created within the context of a specific industry, those steps can be abbreviated here. The potential customers for the technology are limited to those who test wet concrete to verify its compliance with ASTM standards and guidelines adopted by concrete contractors themselves. The three sets of potential customers analyzed by the team of students, listed below, frame a set of customer demands. Of course, the ultimate goal of commercialization is not the customers themselves, but their decision to buy a new product or service.

- Small-scale concrete contractors: Contractors who work on jobs consisting of single houses, driveways and sidewalks, small multi-unit structures, and sets of up to 20 units.
- Large-scale concrete contractors: Contractors who specialize in large retail projects, apartment communities and single family developments.
- Self-consolidating concrete (SCC) producers: SCC, available in the US since 1998, is a low-viscosity form of concrete whose chief use is in pre-fabricated bridge supports and building structures.

Regulations, current competitors, cost limitations, performance guidelines, and standards all drive customer demands. Those demands characterize what will determine the buying decision of a particular customer. The key for identifying demands is to capture what is valuable and what problems exist for potential customers. The team examined industry publications, contacted concrete industry trade associations, and later talked with several concrete producers and contractors to determine the key demands and capture the buying decision of each potential customer. The most important demand factors and demands are illustrated in Fig. 4. The customer demand factors (represented by the boxes numbered D1-D9) directly relate to key customer demands. For instance, the customer demand for box D1 is "Require simplicity," the demand for box D2 is "Require cheap test," and the demand for box D9 is "Require test for full range of products". In this figure, additional demands and demand factors that could be listed are left out for clarity. The buying decisions of the three potential customers, small-scale concrete contractors, large scale contractors and SCC Industry are represented by Boxes M1, M2 and M3 respectively.

Because of the superiority of their technology, the student team initially considered small-scale contractors to be the most promising market. Boxes D1, D2 and D4 indicate this hypothesis was not supported by their research. Further, the contractors are required to follow the slump test (Box D3) by regulations that can supersede performance or cost demands. The demand factors in Fig. 4 clearly illustrate that only one of the benefits of the technology matches with the pictured customer demands. The universality of the rheometer technology could consolidate the various tests currently used in the SCC industry. While the SCC Industry would like to serve the industry segments engaged in building houses and commercial buildings, no established tests, such as the ASTM C143, validate the long-term performance required for these applications. Further, the

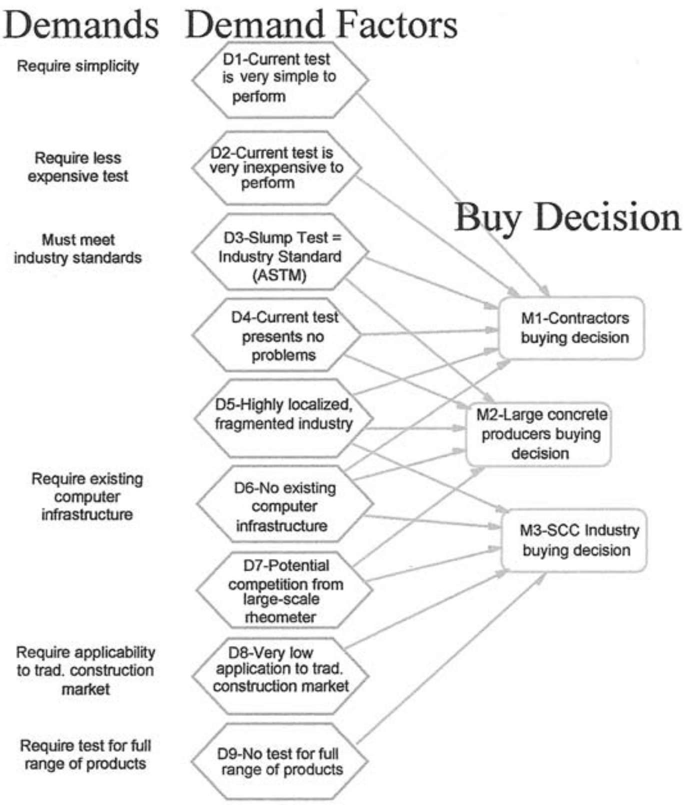

Fig. 4. Customer demands and demand factors.

rheometer is not required for the current applications of SCC.

Consider the difference in perceived innovation opportunity illustrated by Fig. 3 compared to Fig. 4. The concrete rheometer appears to be superior technology compared to the slump test in many ways. A better technology seems to indicate an opportunity with concrete contractors. However, when the regulations and demands of the selected potential customers are considered more carefully the story is very different. Neither of these views is correct.

4. INTEGRATING THE VALUE CHAIN SURROUNDING POTENTIAL CUSTOMERS

Michael Porter introduced a widely applicable value chain model in 1985 [10]. He organized several existing concepts into one system for categorizing the value-creating activities associated with bringing goods and services to customers. Porter's system is traditionally used to describe the activities that connect the procurement of raw materials to the distribution of products to customers. The concept has been extended to include larger systems, services and more recently, innovation itself [11]. For each function in the chain the costs and value created are both determined. In practice, the creation and analysis of value chains is often a comprehensive and detailed effort. The concept of a value chain is used at a more abstract level for the present discussion. The point is to capture the basic network of value creation surrounding potential customers. Within that network related potential demands can be identified. The concept of a customer value chain can have a significant influence on the links that can be formed between technologies and customer demands.

Customer research included examining the value chain surrounding the concrete contractors introduced above. This value chain can be illustrated in a function map, shown in Fig. 5. Concrete contractors are responsible for installing concrete (Box VC13) and for verifying the slump of the wet concrete (Box VC12). That slump test is specified by the ASTM C143 specification (Box VC11). The concrete is mixed and shipped to the job site by a concrete producer (Box VC9 and VC10). The cement (Box VC7), sand and aggregate that form the dry mix are produced local to the job site, sometimes by companies other than the concrete producer.

In recent years the limited availability of natural sand has driven aggregate producers to make sand by crushing rock (Box VC2). The crushing process creates fines or very small particles (Box VC4) that do not inhibit the performance of the concrete, but do undermine the slump test. The fines are washed out of the manufactured sand and aggregate products (Box VC3) before they are shipped to the concrete producer. Washing is a costly process (Box VC5) considering the main cost of the sand and aggregate in the concrete is shipping it to the concrete producer (Box VC6). Finally, the base

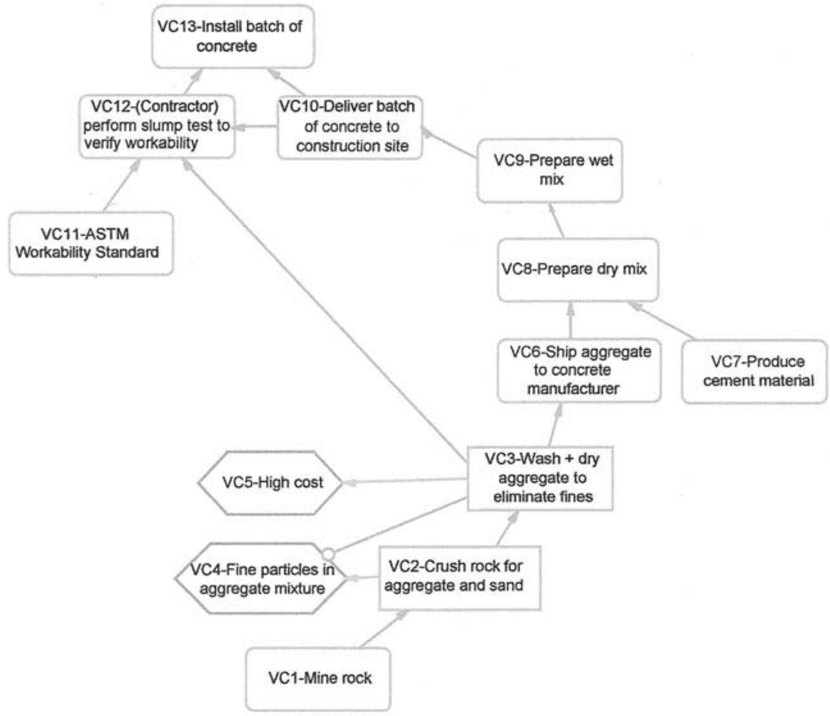

Fig. 5. Concrete value chain.

material for the aggregate and manufactured sand is mined (Box VC1). The SCC industry is not a part of this map.

One assumption contained in Fig. 4 is that the contractors were the only group associated with the slump test. Instead, aggregate producers are facilitating the test by washing the fines out of the aggregate and sand that they produce. This means that there is another customer demand to consider. Aggregate producers would benefit from replacing the slump test. This is illustrated by Box D10 in Fig. 6.

Further, Fig. 4 contains the assumption that the contractors filled all of the roles of a customer. Customers often pay for, benefit from, and use products at the same time. At other times these

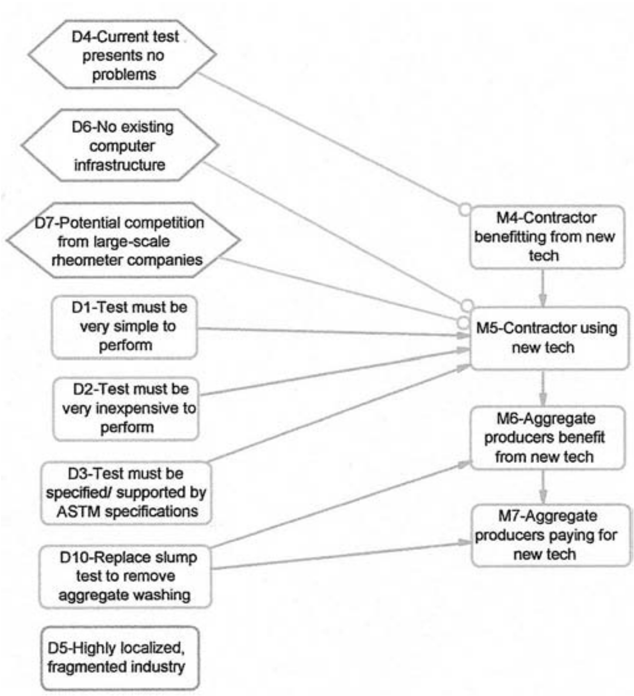

Fig. 6. New demand and broader customer scope.

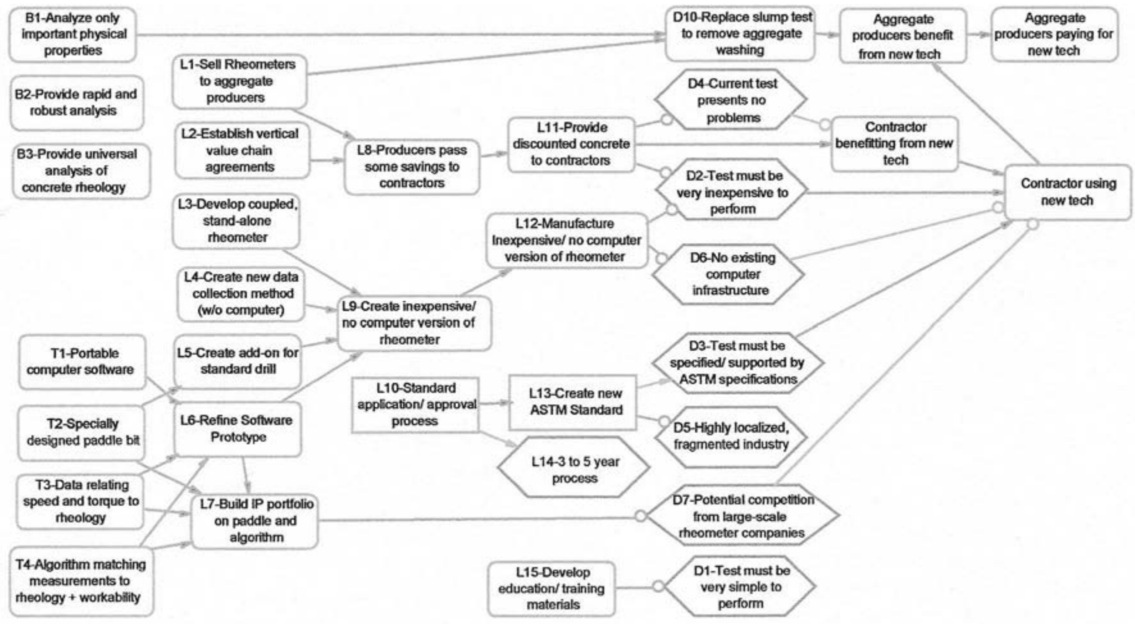

Fig. 7. Links between rheometer technology and customer demands.

roles are divided among different groups. The contractors would certainly *use* a new type of test (See Box M5 in Fig. 6), but aggregate producers would benefit (See Box M6 in Fig. 6). Aggregate producers might be the ones to pay for a new concrete testing device (Box M7), but there must still be some benefit provided to the contractors for them to adopt a new and more complex test. In other words, the consideration of the value chain helps to more broadly define customers, customer roles and customer demands.

5. CREATING LINKS FROM CUSTOMER DEMANDS TO A TECHNOLOGY

Technology innovation requires links between a technology and customer demands. For the concrete rheometer technology these links will connect the benefits and technology elements illustrated in Fig. 1 with the demands illustrated in Boxes D1, D2, D3, D4, D5, D6, D7, and D10 in Fig. 6. The process of building those links follows a similar pattern to the creation of the technology map in Fig. 1. Negative demands, such as the lack of computer infrastructure (Box D6) need to be counteracted. Positive demands, such as replace slump test to remove washing (Box D10) should be produced by functions. Then the sub-functions can be added in turn by returning to asking how each function is produced. At some point the technology elements are required for a particular sub-function. The process of forming these links is illustrated for the concrete rheometer technology in Fig. 7. The benefits and technology elements are found in the left column (Boxes T1 through T4 and B1 through B3). The demands from Fig. 5 may be found to the right, also in a column (Boxes D1 through D10). The customer decisions (Boxes M4, M5, M6 and M7) are found to the right of the demands. Each demand is addressed in this example by at least one function. In practice it is possible that some demands will not be addressed. Each of the technology elements are connected to the network of links.

Note that Fig. 7 is representative, not comprehensive. It could include more detail within the links and additional links. It is also important to consider that the network shown is not unique. The demands could be addressed in alternate ways. Still, the relatively simple network in Fig. 7 illustrates how the links between a technology and customer demands facilitate technology innovation. Since replacing the slump test is valuable to the aggregate producers they could assume part of the role of a customer. The rheometers could be sold to the aggregate producers, but would still be used at the job site by contractors. One possible incentive for the contractors to learn and use a new test would be to offer discounts on their concrete by way of the concrete producers. Boxes L1, L2, L8 and L11 connect these functions together. It is likely that the concrete market will still be sensitive to the cost (including reliability) of a rheology testing product. Lowering the cost could be addressed by manufacturing a new tester that works with standard hand drills and requires no computer (Box L12). The tester would need to be created (Box L9). It would also require software development (Box L6) and work to develop the individual components of the system (Boxes L3, L4 and L5). Further, software development would require the current software (Box T1) and the development of a new sensor would stem from the current paddle bit (Box T2). The functions supporting the new tester establish a link from the demands shown in

Boxes D2 and D6 to technology elements (Boxes T1 and T2). This link can be considered as an element in an innovation roadmap that guides further consideration of the risks and costs associated with innovation. Intellectual property development is the other link in Fig. 7 that illustrates such a connection (Box L7).

The benefits of the technology can be connected directly to demands. The ability of the rheology technology to read concrete flow properties in the presence of fines is critical for eliminating the washing step for aggregate producers. This is illustrated by the link connecting Box B1 to Box D10. One could argue that the rapid and robust analysis of the technology (Box B2) should be connected to the creation of an inexpensive version of the tester (Box L9) or could address the demand of a low cost testing device (Box D2), directly. Either of these would be perfectly viable connections. The third benefit of the technology (Box B3), on the other hand, does not participate in the network.

6. DISCUSSION

In this paper two steps of the TIM tool are emphasized; characterizing the technology and building the value chain related to a chosen customer. By looking at the benefits and technology elements one level of understanding about commercialization opportunity is expressed. The concrete rheometer is superior to the slump test. Another is gained by performing market research about the customer. Contractors do not have any demands that indicate a need to replace the slump test. The value chain related to concrete provides a third perspective on the potential links between a technology and a market. Aggregate producers are forced to perform a costly washing process so contractors can test the concrete using a slump test. Once the value chain is considered, several links between the value chain and the technology can be formed which outline several activities required for the rheometer technology to reach customers in the concrete industry.

The concept of a value chain supports a more complex definition of "customer." The customer is often considered a user, buyer and beneficiary jointly. Combining these roles together limits the source of customer demands to the contractors themselves, as illustrated in Fig. 4. When the value chain is integrated into this example, the concept of "customers" expands to include aggregate producers and several different roles. The value chain also provides a framework for rapidly building a broad understanding of this larger definition of a customer. Similarly, the larger framework of the TIM tool provides a framework for understanding the technology and integrating knowledge into an understanding about the links that connect a technology and customers. Those links form an outline of both an opportunity and how that opportunity may be realized.

The current discussion was based on taking existing customer research and populating the maps that form the TIM tool. The next step for the development of the TIM tool is to examine its use during the research process.

Acknowledgements—The development of the TIM Tool is supported by a National Science Foundation "Partnerships for Innovation" grant #0650249. The authors thank Dr. Luz Cristal Glangchai for her editorial input in preparation of this paper and for the re-creation of all figures in the document. The figures in this paper were originally created using the Guided Innovation Toolkit software created by Pretium Consulting Services, LLC. The authors are grateful for their donation of software to this project.

REFERENCES

1. R. S. Evans, D. C. Bonner, S. Y. Malkin and S. P. Nichols, Addressing the "Innovation Gap" for Engineering Education: A Mapping Tool, *Innovations 2008: World Innovations in Engineering Education and Research,* iNEER, Arlington, VA, 2008, pp. 519–38.
2. A. Schupak, The Mind's Cartographer: Functional brain mapping of fruit flies. *Forbes* **176**(10), 2005.
3. B. Marr, G. Schiuma and A. Neely, The Dynamics of Value Creation: Mapping your intellectual performance drivers. *Journal of Intellectual Capital*, **5**(2), 2004.
4. S. Wantanabe, T. Noda and Y. Kawoaka, Functional Mapping of the Nucleoprotein of Ebola Virus. *Journal of Virology*, **80**(8), 2006.
5. K. Otto and K. Wood, *Product Design: Techniques in Reverse Engineering and New Product Development*, Prentice Hall, Upper Saddle River, NJ, 2001.
6. B. Holmes, Beyond Words, *New Scientist*, **163**(2194), 1999.
7. ASTM Standard C 143, Standard Test Method for Slump of Hydraulic-Cement Concrete, ASTM International, West Conshohocken, PA, www.astm.org
8. S. P. Nichols, N. Kaderlan, J. S. Butler and M. A. Rankin, An Interdisciplinary Graduate Course in Technology Entrepreneurship. *Proceedings of the ASEE Annual Conference and Exposition*, Session 2354, Montreal, Quebec, Canada, June 16–19, 2002.
9. A. E. Chakrabarti, *Engineering Design Synthesis: Understanding, Approaches and Tools*, Springer-Verlag, London, 2002.
10. M. Porter, *Competitive Advantage: Creating and Sustaining Superior Performance*, Free Press, Simon & Schuster, New York, NY, 1985.
11. M. T. Hansen and J. Birkinshaw, The Innovation Value Chain, *Harvard Business Review*, June 2007, pp. 121–30.

R. Scott Evans is the consulting business director for Pretium Consulting Services, a company that creates structured innovation systems and software for technology companies. He previously instructed cross-listed graduate-level courses in technology commercialization and coordinated the Idea to Product® technology commercialization program. He co-founded a materials and manufacturing company based on his Ph.D. research, which partially funded his doctoral studies. His industrial experience includes manufacturing and product engineering for Reynolds Industries and Thermax/CDT, Inc. His research at The University of Texas and Georgia Tech included technology entrepreneurship, product design, MEMS, materials science, and manufacturing.

Steven P. Nichols is a Professor of Mechanical Engineering at The University of Texas at Austin. He also serves as the Director of the Advanced Manufacturing Center, the Director of the Chair of Free Enterprise, and an Endowed Fellow of the IC2 Institute. As the Director of the Clint Murchison Chair of Free Enterprise, he focuses on creating and nurturing a culture of technology innovation, creativity, leadership, and entrepreneurship at the university. He is a member of the New York Academy of Sciences and a Fellow of the American Society of Mechanical Engineering.