Int. J. Engng Ed. Vol. 26, No. 3, pp. 735–743, 2010
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Creating Customers for Technology Using a New Mapping Tool*

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A Technology Innovation Mapping (TIM) Tool has been introduced in previous papers. The TIM Tool organizes the process of linking customers and technologies into a series of steps. The tool can be used by engineers, engineering, and others involved in technology commercialization. This paper focuses on the steps that organize the task of creating potential customers for a technology. The authors present an example technology to illustrate the key concepts of the TIM Tool.

Keywords: technology commercialization; innovation; function mapping

1. INTRODUCTION

> Dr John Hennessy, President of Stanford University stated that many technology commercialization efforts have failed to grasp the importance of having a sustainable advantage, a significant barrier to entry and leadership "when the market and the technology are both ready." [1]

THE FIRST STEP of engineering design methods is typically some form of characterizing customer needs. (See, for example, Pahl and Beitz, 1996 [2]) An emerging technology may be associated with a particular customer or may have no known application. In other words, the customer needs are incomplete or the customer is undefined. Additional tools are necessary to support the creation of products (or services) based on emerging technologies. Fortunately, the process of linking emerging technologies with the needs of customers can be described as a series of steps [3–4] as shown in Fig. 1. The Technology Innovation Mapping (TIM) Tool supports this process.

The TIM Tool has been used to illustrate the concepts of "Characterizing the Technology" and creating a "Customer Value Chain." [3–4]. "Characterizing the Technology" refers to forming a clear understanding of the unique technology elements and benefits of a particular technology. The output of this step is a clear understanding of the benefits and the unique technology elements, abbreviated "B+UTE" in Fig. 1. Another paper introduced how a value chain surrounding a potential customer could be linked to the benefits and unique elements of a technology [4]. A "Customer Value Chain" is a network of value added functions that support and are supported by a potential customer. As defined in Table 1 on following page, the term customer is used broadly in this discussion to include purchasers, benefactors and users.

In this paper the authors introduce Step 2 and focus on the second iteration loop. This loop represents the process of finding and assessing potential customers using value chain maps. The following discussion traces an example through the four steps and three iterative loops of the TIM tool

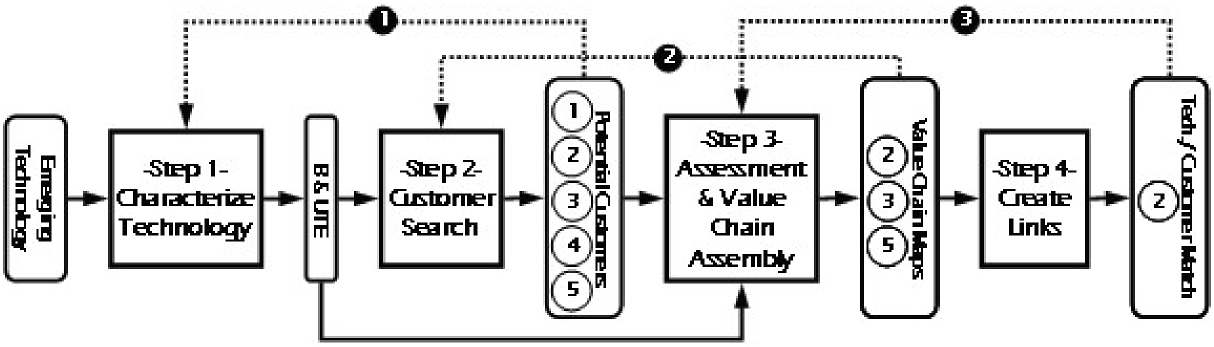

Fig. 1. TIM tool method for finding potential customers.

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* Accepted 28 November 2009.

Table 1. Key discussion terms

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.
Technology Elements	Technology 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.

to illustrate how the tool facilitates the search for and analysis of potential customers. The example also supports more general conclusions about technology innovation.

The authors chose a manufacturing technology licensed from the University of Texas in 2003 to illustrate the second loop in the TIM Tool. A team of students examined the commercial potential of the technology during both engineering and business coursework. During their assessment of the technology they discovered a new application. The new application led to additional university research coupled with the formation of a new firm. Students participated as founders, lead researchers and officers in the new venture [5–6]. Although the TIM Tool was not used during the project, project information can be entered into the tool, illustrating how it can be used. Further, the project provides a baseline for drawing conclusions about how the project could have been altered with the use of the tool.

Several terms used in this paper are assumed to have specific meanings. These key terms are listed in Table 1. The discussion below includes a series of function maps. The maps contain functions that are defined to be both useful (value positive) and harmful (value negative). Useful functions are circumscribed by squares, while harmful functions are circumscribed by hexagons. The functions in those maps are connected by two types of causal relationships; producing and counteracting. Counteracting relationships are represented by lines tipped with a circle. The functions and their causal relationships form networks (or maps) that efficiently represent complex relationships between functions and highlight critical issues.

2. A NEW WAY TO MAKE PARTS FROM SILICON CARBIDE COMPOSITE MATERIALS

Unlike molding operations or machining, additive manufacturing technologies build up solid parts by solidifying fluids (or slurries) or by fusing powders into final shapes. Selective laser sintering (SLS) is an additive manufacturing technology that builds parts from layers of powders [5]. The SLS process has several key steps. A thin layer of powder is spread across a bed of powder. A laser scans (and heats) a region of the surface which fuses a portion of that layer (and to previous fused regions). Each scanned layer forms a cross-section of a 3-D part. Finally, the floor of the bed is lowered to accommodate another powder layer on top of previous layers. These layers typically range from 0.003 to 0.005 inches in thickness. By repeating these steps, a complex 3-D part can be formed a thin layer at a time. One advantage of SLS is that a part can be created without part-specific tooling and directly from a CAD file.

Most current parts manufactured in the SLS industry are made with a particular type of powdered nylon and are used as partially functional or prototype parts [5]. When building nylon parts, all of the powder within the scanned regions is active. Other types of powder used in SLS processing combine active and reinforcing powders. As an example, 40μ glass beads (which appear as a fine powder) are often mixed with the nylon powder to form stiffer glass-reinforced SLS parts. Nylon and glass-reinforced nylon parts are nearly fully dense. Another type of powder mixture is designed to be porous in the machine and later filled with another material to form a fully dense part. One example of such a powder system is a mixture of silicon carbide powder and phenolic. Under the laser, the phenolic flows and holds particles of the silicon carbide. The part formed using this material is a porous part in the shape of the desired final part. This 'preform' can be infiltrated by liquid polymers, such as epoxy or with the use of a furnace, by metals. The infiltrated parts have material properties that cannot be achieved using nylon powder. The combination of SLS to create the part shape with post-processing to create material properties is called Indirect SLS. Part of the value of this Indirect SLS technology is its ability to form parts from silicon carbide. The properties of the material are very

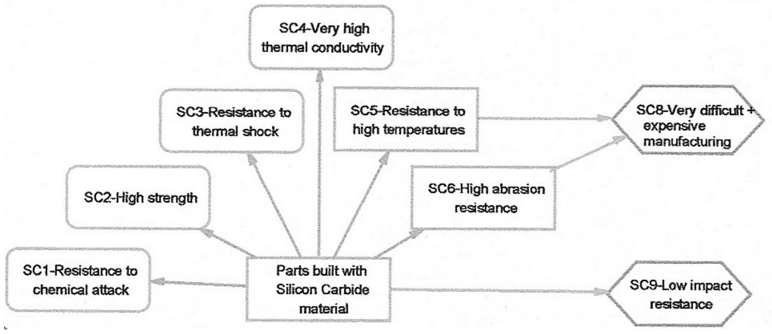

Fig. 2. Silicon carbide properties.

useful, as illustrated in Fig. 2, but it is traditionally very difficult to manufacture parts from the material. Figure 2 shows useful properties of silicon carbide in boxes SC 1 through SC 6. Boxes SC5 and SC 6 help to produce the challenging manufacturing of silicon carbide parts (Box SC8). Finally, though silicon carbide has the strength of steel, it is a brittle material (Box SC9).

The first step in the TIM tool guides the creation of a function map that highlights the benefits and unique elements of the technology. A function map of the Indirect SLS process (for producing silicon carbide parts) is illustrated in Fig. 3 where, 'B' designates "Benefits" of the technology while 'T' designates "Technology Elements." "CT" designates the functions outlining the core technology functions.. The benefits of this manufacturing technology (create complex silicon carbide parts, build them with minimal machining and create them inexpensively) are illustrated by boxes B1, B2 and B3. The unique elements of the technology are listed in boxes T1 through T6. These include the scientific understanding about how the infiltration process works, the formula for the binder and powder mixture and how to set up the SLS machine to effectively build perform parts. The benefits and unique elements of the technology are connection points for links to potential customers and associated value chains. In other words, what the technology does that can be valued by a customer and what is unique about it are critical for the early stages of technology commercialization. The details about how the technology works (illustrated in Boxes CT1 through CT24) are not. Still, it is important to consider the two functions labeled as harmful in this diagram, CT5 and CT2.

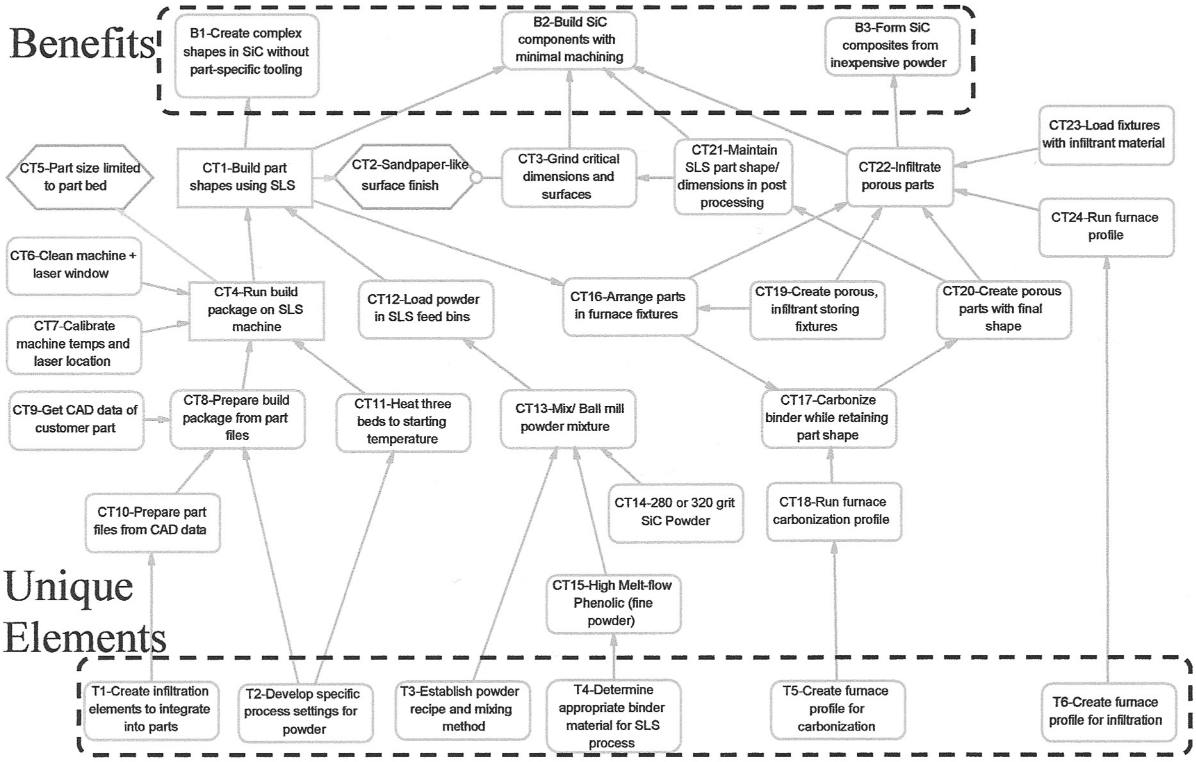

Fig. 3. Indirect SLS fabrication of SiC components.

The size of parts and the surface finish that can be produced using this technique are both limited. The line tipped with a circle connecting box CT3 to box CT2 indicates that grinding critical dimensions and surfaces counteracts or impedes the sandpaper-like surface finish.

The information represented in Fig. 3 was created over a period of more than two years during master's and doctoral research projects. Further, the benefits and the unique technical elements were realized through research into potential customers, competing technologies, and existing intellectual property. While a significant amount of work is represented in Fig. 3, it is represented in a way that is easily understood by someone unfamiliar with the technology.

3. ASSESSING A POTENTIAL CUSTOMER

For a particular technology, the set of all potential customers is bounded by individuals or organizations for which at least one benefit is especially valuable. In other words, it is potential customers who determine what functions of the technology form benefits (illustrated by Fig. 1). A sensor technology developed for the sole purpose of analyzing the structure of concrete may be closely tied to potential customers within the concrete industry. An electronic paper technology could have customers spanning dozens or hundreds of industries and applications. In either case, developing an understanding about the technology benefits and the value chains associated with potential customers is an iterative task and is supported by the maps and steps of the TIM tool.

The technology illustrated in Fig. 3, was developed for a particular customer. The vision for the technology was to produce semiconductor wafer fixtures for high-temperature furnace processes. The value chain created from information collected during the analysis of the technology is illustrated in Figure 4. This value chain is a subset of the manufacturing chain for semiconductor wafers. Wafers are prepared in a variety of ways before furnace processing (Box IC21 where "IC" designates functions related to integrated circuit manufacturing). During furnace processes for wafers heat is applied (Box IC9) with a particular process gas (Box IC22). The temperature follows specific ramps and dwell times (Box IC19) and needs to be very uniform across the wafers (Box IC16). Since total dwell times can reach several hours, multiple wafers are processed at the same time (Box IC11). Furnace processes are used for dopant activation, dopant diffusion, and thermal oxide growth as shown in Boxes IC2, IC3 and IC4 respectively. These prepare wafers for subsequent processes (Box IC1).

Wafer processing also has many challenges. They are illustrated in Fig. 4 as harmful functions. The temperatures needed for wafer processing

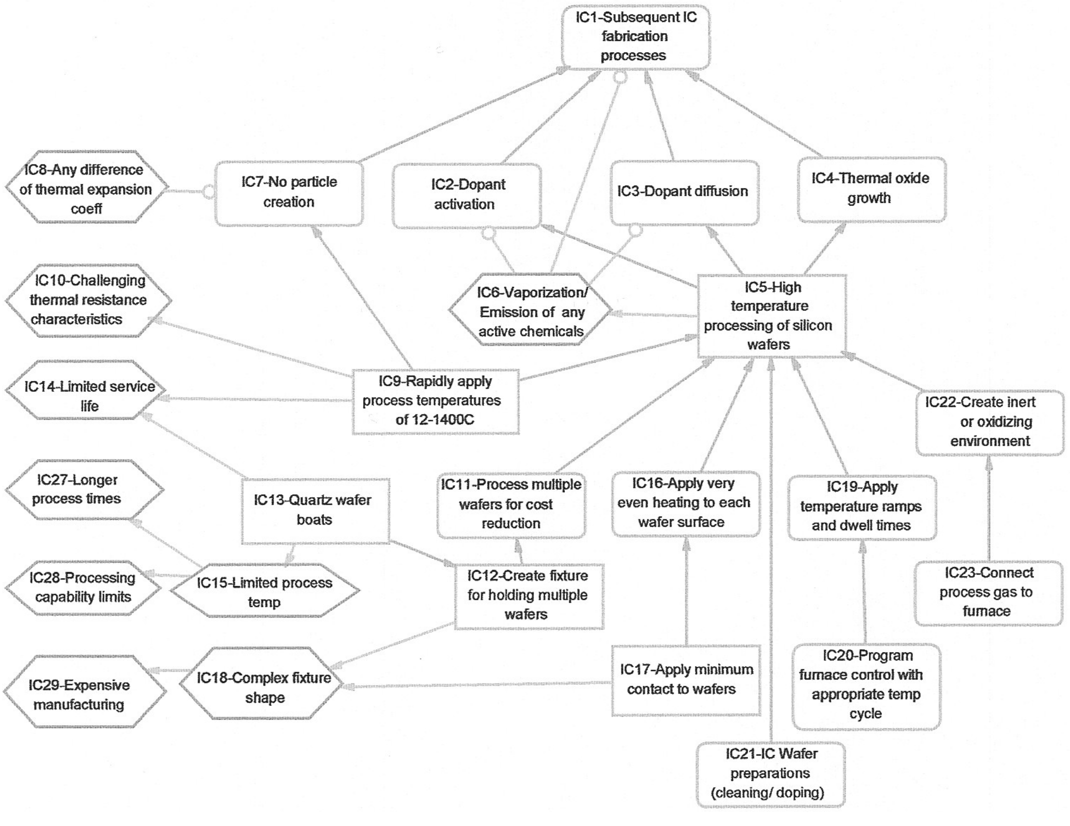

Fig. 4. Value chain for wafer furnace fixtures.

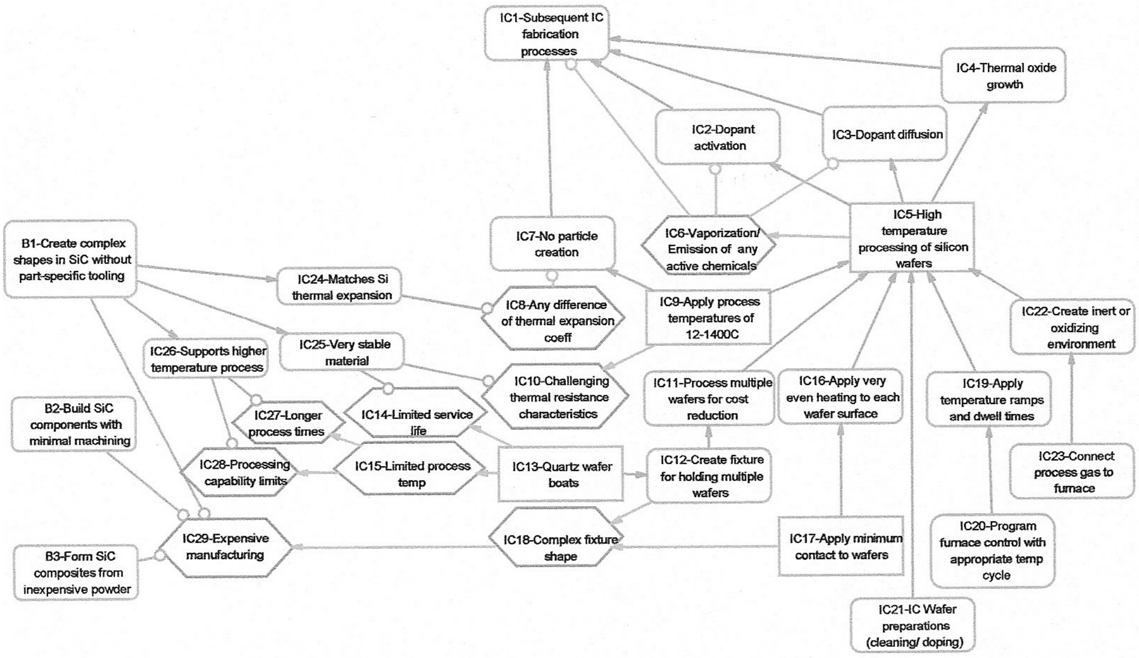

Fig. 5. Connecting benefits to IC manufacturing.

require ceramic fixtures (Box IC10). Any electrically conductive materials present in the furnace (Box IC6) or differences in thermal expansion between the fixture and the wafer (Box IC8) (which create particles from abrasion) can harm the manufacturing processes and future electrical circuits on the wafer. The industry standard quartz material imposes limits on the process temperature (Box IC15) which in turn limits process capabilities and times (Boxes IC28 and IC 27, respectively). The thermal shock and cycling of the process temperatures combined with the quartz material limit service life. Finally, manufacturing quartz fixtures is expensive (Box IC29) due to the complex shapes required to maintain uniform processes and minimal wafer contact. Similar to Fig. 3, Fig. 4 also represents significant research, but quickly highlights the demands of customers.

The function map in Fig. 4, represents customer information considered before and during the development of the technology. Consider how the benefits in Fig. 3 could be connected to the harmful functions illustrated in Fig. 4. As an example, silicon carbide's high resistance to thermal shock would facilitate a longer service life compared to quartz. The application concept was to replace quartz fixtures with silicon carbide and to replace costly precision grinding operations with the shape creation capabilities of Indirect SLS. Silicon carbide composites would allow higher temperature (faster) processes and lower particulate generation. Traditionally, manufacturing parts from silicon carbide is extremely expensive, but silicon carbide powder is inexpensive. Building parts from this inexpensive powder would also provide lower cost fixtures. The match between the technology and wafer fixtures seems very strong. The discussion of this match won nearly \$1M in research funding from the National Science Foundation and a Texas Technology Development and Transfer Grant (More information about the TDT grant program may be found at http://www.arpatp.com/). As illustrated in Fig. 5, almost all of the harmful functions are counteracted by the benefits of manufacturing silicon carbide wafer boats with Indirect SLS techniques.

In 2003, the team examined the match between Indirect SLS and wafer fixtures for high-temperature semiconductor processing and added information to the value chain and to the understanding of the technology. The additional information, illustrated in Fig. 6 on the following page, indicates that while many of the harmful functions in the value chain could be counteracted, it is unlikely that the semiconductor industry contains potential customers. This is due to three critical pieces of information. First, there is a very large investment of both time and money to introduce new materials and processes into the semiconductor manufacturing (boxes IC32 and IC33). While semiconductors are valuable, the fixtures used for a few of the hundreds of processes in their manufacture do not represent significant value per se. On other words, the time and money cost of qualification is disproportionate to the ultimate value of the fixtures within the total value chain of the semiconductor devices. Second, the trend in semiconductor manufacturing at the time was away from batch processing and therefore away from the need for complex fixtures. Finally the current Indirect SLS process imbedded carbon throughout the parts. Carbon is electrically conductive and diffuses through solid material at high temperatures. This combination effectively eliminates the technology from consid-

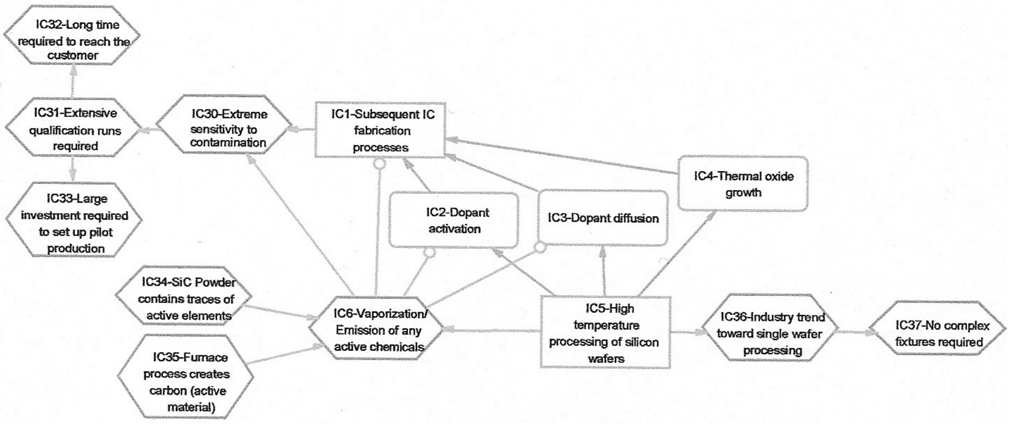

Fig. 6. Additional information about IC manufacturing.

eration for semiconductor processing (its original intended purpose).

Illustrating information in this way assists product designers in combining information spanning many different disciplines. In Fig. 6, materials science, business trends, and R&D guidelines are easily combined into a single diagram. In contrast, university researchers, entrepreneurs, and funding agencies who participated in the development of the technology over several years did not recognize how inherent features of the technology could create significant problems in the value chain of potential customers in the semiconductor industry. Jolly outlines the challenge associated with having insight into both the technology and potential customers simultaneously (using the term "techno-market insight"), in his book [7]. Steps 1, 2, and 3 of the TIM tool support understanding in these areas simultaneously.

3.1 Returning to Step 2

The team realized that there may not be opportunity for Indirect SLS in semiconductor fabrication. While reaching that understanding, the team also began to understand the benefits and unique elements of the technology. They sought other applications where potential customers would value the benefits of the technology. The question they had to answer was related to who needed the properties of silicon carbide (see Fig. 2) in a complex shape? They also realized that the relatively low cost available using the indirect SLS technology to produce silicon carbide components might open new applications. Among the applications they considered were heat exchangers, static mixers, engine components and metal processing equipment.

One of the applications the team generated was metal casting dies, the mold shapes or tooling that are filled with molten metal to cast complex metal parts. The information the team collected about aluminum die casting can be organized into a value chain map, shown in Fig. 7 on the following page. The main steps involved in casting aluminum components may be found on the right side of Fig. 7. These include seal dies (Box MC17), fill part shape with aluminum (MC10), cool part (MC 7) and release part (MC 5). The purpose of these steps is to produce parts with a low cost (MC2).

The figure clearly indicates potential connections to customers in aluminum die casting. The long cycle time (MC9) is partly due to the thermal conductivity of tool steel. Silicon carbide has roughly double the conductivity of tool steel. Creating complex shapes in tool steel is a costly, time consuming process (MC21). Perhaps forming parts using SLS could be faster. Further, the trend in US die casting is toward higher complexity. There is also risk that can be identified as well. Current die casting operations require high toughness materials (MC24). When information from potential customers is organized into a value chain map the possible links from a technology can be considered readily.

Figure 8 on the following page demonstrates possible connections between the benefits and the value chain. It includes functions from the properties of silicon carbide illustrated in Fig. 2, from the benefits of the Indirect SLS technology illustrated in Fig. 3 and the harmful functions illustrated in Fig. 7. The main harmful functions illustrated in Fig. 7 (MC9, MC12, MC29 and MC27) are counteracted by the benefits of the Indirect SLS technology. Additional information about loading and abrasion in the process (MC31, MC32) are counteracted by the properties of silicon carbide, with the exception of impact loading (MC33). This unmatched harmful function represents a need for further innovation.

By bringing material properties, the features of a new manufacturing technology and customer needs into the same diagram the complex interaction between the information in these areas can be quickly assessed. In contrast to the diminishing needs of the semiconductor customers considered above, metal casting has a very large and increasing need to reduce lead times and lower production costs. The next step is to examine how the new technology could be integrated into the value chain for metal casting. When mapped, the functions

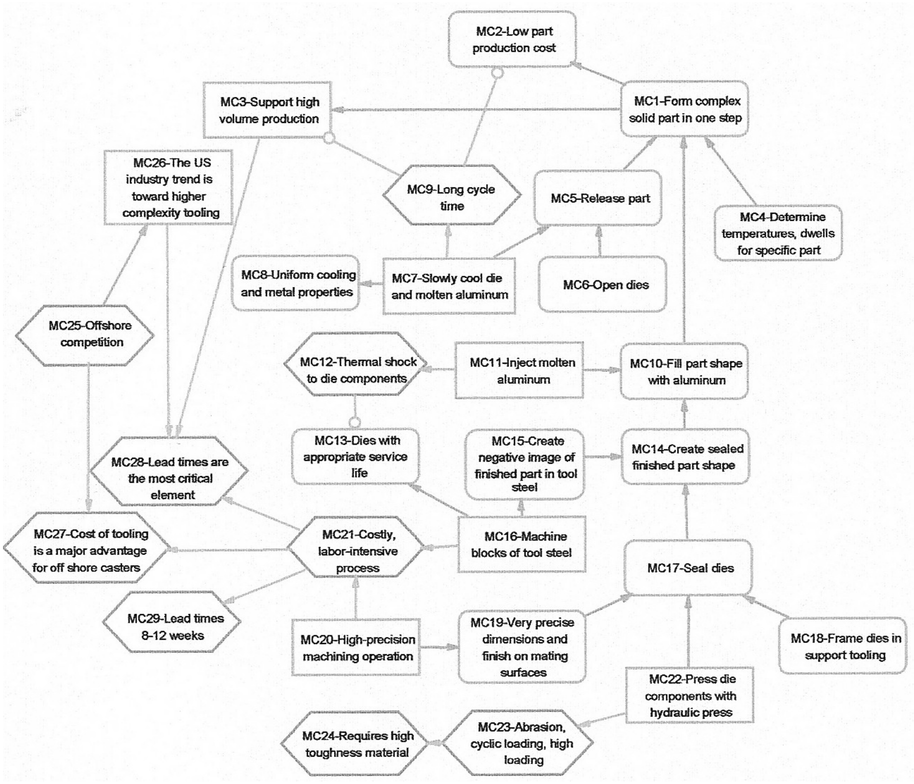

Fig. 7. Aluminum die casting value chain.

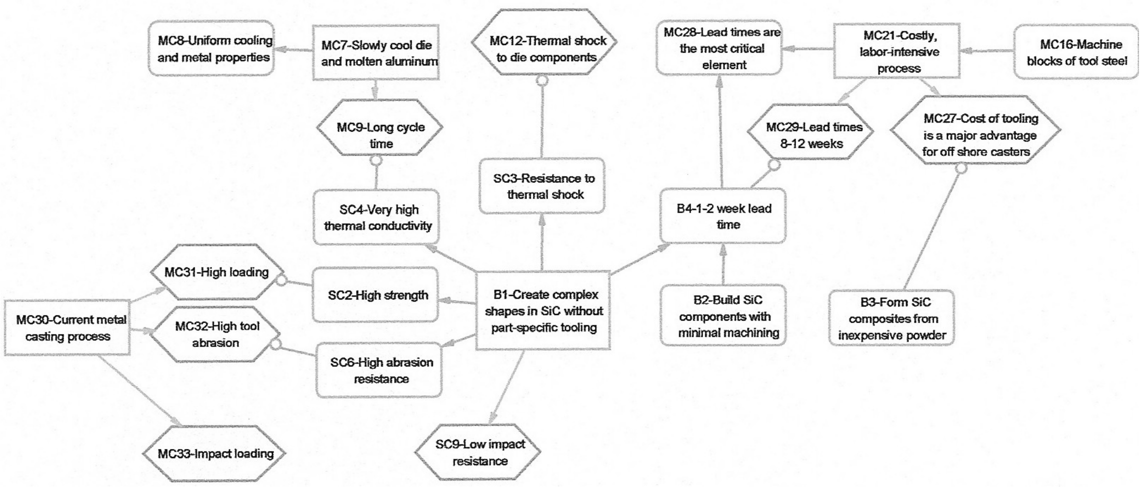

Fig. 8. Assessment of aluminum die casting customers.

that describe this process form the links between the technology and the customer value chain introduced at the beginning of this paper.

3.2 Step 4: create links

The unique technology elements previously introduced represent the current state of the technology. Matching the benefits of the technology to the needs of a potential customer provide a quick preliminary assessment. The more challenging task is to understand the main tasks that connect the current state of the technology to the point of customer purchase. The authors call these chains of tasks the "links" between a technology and a potential customer. (The process of building these links is discussed in another paper by the same authors.)

The links between the Indirect SLS technology and potential customers in the metal casting market are illustrated in Fig. 9 on the following page. They connect the Unique Technology Elements (T1 through T6) on the left side of the map to the needs of potential customers in Metal Casting, shown in the "MC" boxes on the right side of the map. Three boxes in particular illustrate the purpose and content of these links.

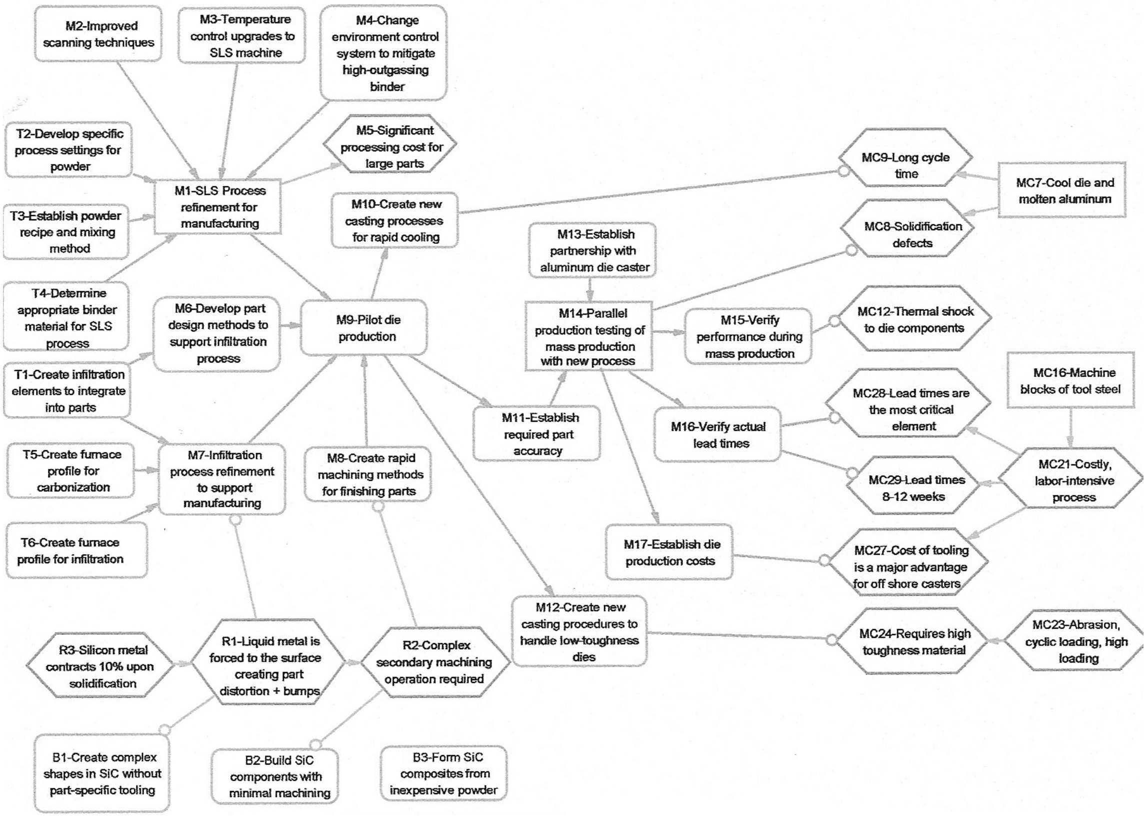

Fig. 9. Connecting the technology to the value chain.

Setting up a new manufacturing process requires pilot tests. This is reflected in Box M9, "Pilot die production." The functions leading into this box describe how that pilot production would be setup. One of the boxes that connects to M9 is M1, "SLS process refinement for manufacturing." SLS is a prototyping technology while manufacturing requires high repeatability with low human support. Creating a manufacturing capability would draw on several of the current technology features (T2, T3 and T4), but also several other developments as well (See M2, M3 and M4). Box M9 leads to "Create new casting procedures to handle low-toughness dies" (Box M12). The tasks in the links include activities to resolve challenges identified during earlier TIM Tool steps.

4. RESEARCH AND ITERATION

One of the features of the TIM Tool is that additional knowledge can be integrated into the maps. This facilitates understanding how that new knowledge changes the opportunity represented by the match between the technology and potential customers. Several of the research findings are illustrated in Fig. 9. New understanding about a technology can be added to function maps. In Fig. 10, additional research information is shown to have a more serious effect on the benefits of the technology. Parts built using the new technology showed complex, multi-dimensional distortion (Box R4), non-uniform material properties (R5) and much weaker material than expected (R6).

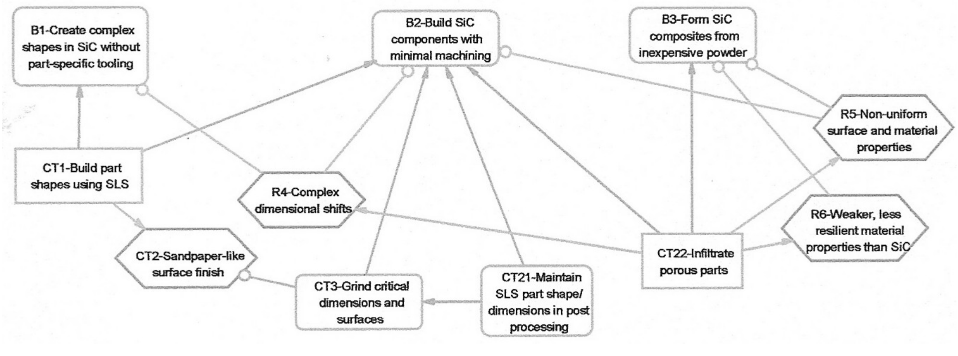

Fig. 10. Integrating new technology information.

While the research resulted in new technical understanding, that new knowledge showed that additional technical challenges would need to be overcome before parts could be manufactured for customers.

5. CONCLUSIONS

This paper describes steps in the use of the TIM Tool and illustrates the iterative sub-process of creating potential customers for a given technology (see Loop #2 in Fig. 1). The example presented illustrates several strengths of the TIM Tool. First, the tool supports understanding how a technology and customer might be linked by facilitating the integration of business, technical and engineering information. The TIM Tool allows these different sources of information to be integrated into a single cause and effect analysis. The tool also facilitates focusing on the most critical information for this analysis. Finally, the tool promotes team understanding and team innovation.

Without the tool, the project described in this paper pursued the semiconductor market for several years and a new company was created to pursue an alternate method for creating metal casting dies. As of the completion of this paper, no commercialization activities related to the Indirect SLS of silicon carbide are being pursued. Using the tool, and information available at the time, several significant issues related to the links between the technology and customers are made more apparent. It is possible that the research would have followed different and possibly more valuable path if the tool had been used.

The TIM Tool facilitates the creation of connections between the technology elements and benefits of the technology and a value chain that helps identify customer needs. This additional activity is necessary to support engineering activity where customer needs are incomplete. Part of this capability stems from the integration of information from many disciplines into a single analysis. The maps and steps form a common language for realizing links from technology capability to customer needs. The links provide a basis for understanding opportunities and risks related to the creation of products and services with a particular technology. Those opportunities involve the creation of customer needs, in contrast with traditional engineering design where customer needs are the input to the 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 Figures 2 through 10 in the document. Figures 2 through 10 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.

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