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Vision

“Be the world’s premier institution of manufacturing research, development and deployment powered by talent, innovation and passion.”

WHY MANUFACTURING MATTERS

There is abundant evidence that manufacturing is a critical sector of a nation’s economy for building wealth. A number of studies from governments, corporations, policy institutes and academic institutions support this assertion and indicate that “making things” is an important way to improve a society’s standard of living. Without a healthy manufacturing segment, nations spend their wealth obtaining goods versus receiving wealth for producing and exporting goods.

Manufacturing benefits the United States specifically as follows:

- 70 percent of U.S. exports consist of manufactured goods;
- One manufacturing job produces up to six additional jobs in the general economy;
- 66 percent of U.S. scientists and engineers are employed in manufacturing;
- More than 50 percent of the national research and development expenditures are made in manufacturing; and
- 90 percent of patents are credited to the manufacturing sector.

A robust manufacturing sector is also critical to a country’s national security because modern militaries rely on advanced weapon systems and communication platforms. Without the knowledge, ability and resources to manufacturing these items, defensive postures become much weaker. As military supply chains increasingly rely on entities outside of their borders, the ability to obtain the best possible components and systems that are unavailable to others becomes extremely difficult. Often, the invention required to conceptualize new products takes place in an industrialized country such as the United States, and the manufacture of the products is then sent to another country that has lower labor rates in effort to reduce the total cost of the product. Outsourcing production of a nation’s military weapons and creating industrial commons for these products in other countries greatly weakens national defense long term.

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Mission

To sustain Georgia Tech’s global leadership in manufacturing innovation and societal impact by:

1. Developing and growing a community of experts who are passionate about innovative manufacturing and how manufacturing will enhance the standards of living, innovation and national security;
2. Defining grand challenges – technological, societal or policy – that affect manufacturing of the 21st century; and
3. Identifying and building missing capabilities to meet manufacturing grand challenges in the 21st century.
Grand Challenges

At the national level, there are two grand challenges facing U.S. manufacturing. The first is how we speed up innovation by rapidly turning research results into innovative products. Today’s research translation takes too long, costs too much, and the results are too random. The second challenge is to establish a national strategy of “invent here – build here.” In other words, it is critical to ensure that what is invented in the United States is made in the United States. Conquering these grand challenges will catalyze advanced manufacturing, and it will act as a vital component for developing a national innovation policy.

**GRAND CHALLENGE NO. 1: ACCELERATE INNOVATION**

According to a recent White House presentation on the Material Genome Initiative (MGI), on average, it takes 20 years for a new material to mature from bench top to market, if it ever reaches the market at all. Cited materials included Teflon, Velcro, Li-ion batteries, and many other familiar materials that we use on a daily basis.

A good example of this particular challenge is seen in the defense sector. Although defense is a high-tech industry, the 2006 annual review of the major defense acquisition programs (MDAPs), found that only 10 percent of the 62 MDAPs were collecting manufacturing process data and 0 (zero) percent were in control of their manufacturing processes, which shows a significant lack of manufacturing maturity. More recently, the 2009 annual MDAP review by the General Accountability Officer, covering design, technology, and manufacturing maturity, showed that almost every MDAP lacked manufacturing maturity. This lack of maturity in all three areas resulted in $300 billion (FY 2010 dollars) of cost overruns, and production schedules were, on average, 22 months behind original estimates.

Similarly, innovation translation lags behind from research universities and institutes as well. Although every major research university or institute produces a large volume of scholarly papers each year in

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regards to new knowledge, the number of patents and licensing agreements do not correlate. The number of scholarly publications by far outpaced those of patents, licensing agreements or royalty income. In other words, the economic or societal impact of new knowledge is nowhere near where it should or can be.

GRAND CHALLENGE NO. 2: INVENT HERE, BUILD HERE

It is a familiar story that once a new product is invented, the inventor often seeks a manufacturer overseas to produce the goods. While there are many factors behind such a decision, a lack of robust manufacturing ecosystems in the United States is a key reason. A manufacturing ecosystem is built on a skilled workforce, a robust infrastructure, a friendly business climate, a good investment community, and a hot bed for innovations. Manufacturing ecosystems, also called industrial commons by Pisano and Shih, provide a cluster of localized, interdependent businesses that offer design, production, distribution, workforce, infrastructure, and investment capabilities to help a business thrive. In other words, a business or new technology cannot prosper in a silo.

Several attempts have been made to build advanced technology products, but many have failed. Take for example two recent companies that had the potential to have a significant impact on society, but ultimately did not survive. These two firms were Solyndra and A123. Each company had received approximately US$500 million in U.S. government assistance, garnered much press, and raised the hopes of many American manufacturers. Both had highly innovative technologies in the clean energy arena – rechargeable batteries for hybrid/electric cars (A123) and crystalline thin films (Solyndra).

Why did they fail? The infrastructure to support these technologies, or the industrial commons, had left the United States years ago. Although the United States was once a leader in battery design and production, for example, the industry followed electronics manufacturing to Asia in previous decades. For A123, the “hollowed out” ecosystem for battery manufacturing that this migration created ultimately led to the company’s demise.

Solyndra’s story took a very similar route. According to Pisano and Shih, “The skills needed to process ultrapure crystalline into wafers and apply thin films of silicon onto large glass sheets” were lost decades

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ago, because the United States outsourced the seemingly mundane manufacturing of semiconductors, power supplies, controllers, and similar components to low-cost economies. The center of knowledge and skillsets, or the locus, of R&D and manufacturing had moved to lower cost locations many years ago.

This migration of ideas, skills and knowledge was viewed by U.S. executives as a simple solution to improve the bottom line for the short term. However, the net result of these “seemingly prudent business decisions” over past few decades was “lost competencies, lost jobs, and lost capacities for the future rounds of innovation” in the United States. In other words, the “graze land” for battery-making, thin film-fabrication and many more foundational technologies has disappeared in the United States. For A123 and Solyndra, there was no support system to provide assistance and nurturing. Developed in isolation, without a manufacturing ecosystem, they did not have a chance to grow and prosper.

As the two previous examples show, it is critical to U.S. economic survival to improve the efficiency and effectiveness of its innovation process, and rebuild its manufacturing ecosystem. Innovations have moved to low-cost countries, taking with them skills, ideals and talents. As the recent recession has proven, the U.S. economy has allowed its manufacturing base to dwindle, creating an economy based on a few core industries such as services. History shows that economies or regions that do not balance their industry mix – manufacturing, services, public activities, and so on – do not stay in the lead and are extremely vulnerable to economic downturns. Therefore, not only does the United States need to move its technologies to market rapidly, but it also needs to make sure that manufacturing of those products stays here in the United States to create middle-class jobs.
The Strategic Framework

To face these grand challenges and achieve its mission, GTMI’s Discover here - accelerate Translation - Build here (DTB)” strategic framework focuses on the concurrent maturation of xRLs – TRL (technology readiness level), MRL (manufacturing readiness level), BcRL (business case readiness level) and ERL (ecosystem readiness level). The purpose of this section is to 1) describe the critical and enabling role that academia has in the translation process in the US and specifically GTMI’s strategy, and 2) explain how the DTB framework tackles these two grand challenges for industrialized countries, including the United States.

GTMI’s goal is to establish institutional actors, including research and development centers like universities, as leaders in focusing interdisciplinary research and providing translational prowess for seamless and capable DTB. In the United States, research-intensive universities such as Georgia Tech have moved toward addressing grand challenges in recent years with the establishment of a cluster of university-level Interdisciplinary Research Institutes (IRIs). The IRIs have a mission that includes facing outward, forming industry and government partnerships, and focusing the translation of interdisciplinary research to achieve real-world economic benefits and societal impact.

GTMI’s DTB framework captures synergies of manufacturing-related expertise, aligns the regional ecosystem with the DTB grand challenges, and establishes enabling industry-government partnerships to accelerate the translation of manufacturing-related research to innovative products manufactured in the United States. This approach also requires the design and deployment of an Operating System to effectively institutionalize this future, or “to-be,” manufacturing innovation process. Figure 1 identifies both the “as-is” and “to-be” characteristics for the DTB innovation, value-creation chain. Recent reports including the White House Advanced Manufacturing Partnership Steering Committee’s report also documented that the national emphasis for both the “discovery of knowledge” and “product development” phases of the innovation chain were satisfactory as compared to the “translation” phase, which was characterized as the “valley of death” or the “missing middle.” GTMI’s strategic framework includes the entire innovation chain but provides high focus/emphasis on the “to-be” translation capability (an integral view of technology,

6 The unique functions and value propositions of Georgia Tech IRIs are discussed in Appendix I.
7 The President’s Council of Advisors on Science and Technology, Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing, July 2012.
processes, methods, tools, infrastructure, policies and skills), and the realistic environments required for meaningful translation of research results to innovative products manufactured in the United States.

GTMI’s analysis of the “to-be” seamless and capable innovation chain focuses on: the **Discovery** of knowledge, **Translation** of capability to the U.S. industrial base that **Builds** products. A number of current capability gaps have been identified including:

**Discovery**: This is predominately the emphasis area of academia. Although, universities treat manufacturing-related research as separate disciplines (e.g., materials, processes, design, modeling and simulation, quality, supply chains, logistics, economics, finance, business, public policy, economic development and incubators), this structure incentivizes individual accomplishments and makes use of intellectual property strategies that are not conducive to collaborations between universities and industry. A seamless and capable innovation
THE STRATEGIC FRAMEWORK

chain requires an interdisciplinary and holistic approach to technology development that is focused on specific product exemplars. Therefore, academia must develop a value proposition for engaging the “missing middle” as a viable “knowledge creation” workspace, and some university policies and practices must be critically examined and properly adjusted. Georgia Tech has addressed this need by establishing new Interdisciplinary Research Institutes (IRIs) that focus efforts across campus on core research areas including manufacturing.

Product Development: This is predominantly the emphasis area of industry. The U.S. industrial base has, for the most part, lost its vertical innovation capabilities in pursuing and transitioning research into products. “Bell Labs” and other similar organizations have been lost to budget cuts and heightened emphasis on quarterly profits. New companies with product vision and a willingness to pursue all the knowledge required for making products are driving transformative innovation. Larger American companies reach into the “missing middle” for information but seldom reach all the way back to collaborate, or understand, the efforts within the discovery phase. Startup companies may reach back into the Discovery phase or may rely on “entrepreneurial researchers” for new products to bridge the gap between discovery and product development.

Translation: In developing xRL, our innovation chain analysis indicated a number of missing capabilities, including: 1) an integrated and concurrent technique to eliminate technological, manufacturing and business risks across the “missing middle;” 2) a method to accelerate maturation in a “realistic product use and manufacturing environment;” 3) an operating system designed to accelerate research translation, and 4) collaboration among the right set of stakeholders. To address these gaps, the following are necessary:

- Integrated and concurrent maturation across the “missing middle” requires measurement of integrated readiness of technology, manufacturing and the business case; identification of gaps in readiness; and implementation of actions to close the gaps.
- A “realistic” environment, also known as a “relevant” or “representative” environment, for accelerating translation requires that both the product operational condition (for instance, altitude, humidity, pressures, temperatures, etc.) and the manufacturing environment (proper validation in lab, scale up, prototype, pilot production, low-rate production, and full-rate production) be incorporated at the proper maturity readiness level.
The Operating System designed for the seamless and capable innovation chain must incorporate a number of features that allow acceleration across the “missing middle,” including: 1) initiation of the exemplar business case at TRL/MRL 2 or 3 to fully engage industry and government in building the business case for the translation of research to real products and 2) identification of a lead university, e.g., Georgia Tech, to act as the translational collaboration agent that has strong interdisciplinary manufacturing-related research and an equivocal commitment to involvement in the “missing middle.” The business case should ultimately provide a “tipping point” at TRL/MRL 6 or 7 where industry commits to product maturation and commercialization. As for the lead university, it may subcontract to other research universities to assure full and robust academic engagement. It should engage the regional manufacturing innovation ecosystem to enable acceleration across the “missing middle” by aligning technical colleges, workforce development, public and private equities, incubation of new startup companies, and Manufacturing Extension Partnership (MEP) for outreach to small and mid-sized enterprises and supply chains.

Recreating a successful entity such as Bell Labs is too expensive for most companies. However, the techniques used by Bell Labs to commercialize research can be recreated on a national or regional level via public-private partnerships. This requires that four critical stakeholders be involved: 1) Universities possessing campus-wide, manufacturing-related interdisciplinary research capabilities, 2) industrial and/or government entities that have demands for new and high-impact products, 3) government and/or industrial entities that will catalyze the translation process with investment, and 4) a non-profit entity that can manage the overall process, act as an unbiased broker, add value to the accelerated translation, and assure that the appropriate space and environment are provided for the collaborators.

**CORE COMPETENCIES OF ACADEMIA IN THE DTB FRAMEWORK**

The above analysis, findings and discussion, led to the current design of the GTMI Operating System (Figure 2). This Operating System is intended to guide the development of the future or “to-be” capabilities that minimize the “missing middle” and replace it with a seamless and capable innovation chain by providing the following:

1. **Knowledge Exchange.** Georgia Tech Interdisciplinary Research Institute findings validate the importance of knowledge exchange among the research participants in an interdisciplinary project team and between that research team and the external customers (i.e., end users). The value propositions of all stakeholders must be articulated, understood and achieved. Within the research team, the key challenge is to align individual research efforts with the interdisciplinary problem.
being solved. In this instance, the manufacturing challenge of acceleration of research into innovative products. Structured Knowledge Exchanges (SKEs) provide alignment and shorten the time required to rapidly move from research to actionable findings and products. The SKE accelerates technology transition by clearly and specifically providing the business, socio, and technical intents, scope and means. All these measureable activities lead to the genesis of a rapidly evolving and compelling business case that is critical to gain successful industry buy-in and a strong market pull.

2. **Intellectual leadership in basic and applied interdisciplinary research.** Strategies and processes are required to inventory the manufacturing-relevant research capabilities (processes, materials, design, quality, process capability, industrial base, supply networks, cost, facilities, workforce, above-the-shop floor capabilities allowing acceleration of translation, business cases, policies, regulations, infrastructure, trade, etc.) and skills across the campus. Georgia Tech is globally recognized leader in many of these discipline-specific research areas. The culture is being tweaked so the correct skills and research efforts are being applied to the manufacturing grand challenges.

3. **Translational leadership for rapid campus-wide synergy and interdisciplinary alignment of internal and external stakeholders to address the manufacturing challenge for specific customer needs.**
   a. Universities must develop methods to address collaboration across industry sectors and engage vital members of manufacturing ecosystems. GTMI will use its internally developed operating system to guide research so it has the highest impact on new products and services for industry and government. It will also be used to determine the vital members of a manufacturing ecosystem needed for high impact. This will be accomplished through close collaboration and engagement of all parties in the sector and ecosystem.
   b. Key to the acceleration strategy is a methodology and tool set for quantifying and mitigating risks to translation acceleration. Early efforts made by the Office of the Secretary of Defense’s Manufacturing Technology Office to understand the risks to Manufacturing Readiness Levels (MRLs) illustrates the importance of including a *systems view* (maturation of materials, design, quality, process capability, industrial base, cost, facilities, and workforce) for determining advanced systems and production readiness. The *systems view* for the GTMI operating concept includes production-focused manufacturing readiness (MRL), technology readiness (TRL), business case readiness (BcRL), and regional ecosystem (ERL) readiness. GTMI calls this set of accelerated translation factors “xRL,” and
many customer-oriented risks are included. One specific example is the inclusion of an evolving business case that is evaluated and updated as other factor gaps are closed in moving from xRL 3 to xRL 7.

4. **Deployment leadership with stakeholders to commercialize innovative products and services.** xRL factors relating to risks in commercialization are a vital part of mitigating acceleration risks, as they point to where gaps exist and measure progress on closing those gaps. The GTMI operating system identifies the method to scale-up manufacturing demonstrations, provide proprietary evaluations, and catalyze start-up companies to mitigate critical capability gaps. Effective interfaces are now being created with the GT Enterprise Innovation Institute and Georgia Manufacturing Extension Partnership to collaboratively integrate them within the value stream and manufacturing ecosystem.

![Figure 2. The GTMI DTB Framework](image-url)
STRATEGY

Strategy

GTMI takes a three-prong strategy to achieve its mission:

1. **Continue Georgia Tech's tradition of excellence in basic research and knowledge discovery in advanced manufacturing.**

   Georgia Tech’s Manufacturing Research Center (MaRC), now known as GTMI, was initiated in 1988 and formally created in 1991 as a consortium of academia and industry devoted to developing cooperative research programs intended to enable American manufacturers to regain and maintain a competitive edge in world markets. Initially the programs were focused on electronics manufacturing processes and materials. Over the ensuing 20 years, an original electronics focus has evolved into an impressive portfolio of advanced manufacturing materials, processes and systems. Georgia Tech’s reputation as a global leader in basic research and knowledge discovery is evidenced by the many accolades it has garnered over the years: Boeing Supplier of the Year Award, Boeing Performance Excellence Award, and Strategic Partnerships with Boeing, Siemens, BMW and many international large corporations.

   The basic research component of GTMI will continue the Georgia Tech tradition of excellence in the following areas: additive manufacturing, bio-manufacturing, clean energy manufacturing, factory information systems, lightweight nano-composites and structures, model-based systems engineering, precision machining, public policy, robotics, supply chain management and logistics, and sustainable design and manufacturing. Prioritization of these and other new areas may be needed in the near future.

   Strategically the basic research phase creates a pipeline of enablers that feed into the translational phase of GTMI to support its industry and government customers and sponsors. To speed up basic research and expand its impact, GTMI will incorporate the following processes into its basic research regime:

   a) Integrated experimental and computational approach for rapid development of materials and manufacturing processes and systems,

   b) Tight integration of modeling, synthesis, processing and characterization to avoid trials and errors,

   c) Campus-wide engagement to promote interdisciplinary research,

   d) Meta-roadmapping – constantly scan scholarly papers, patents, market forecasts and existing roadmaps to 1) predict trends, 2) uncover gaps and barriers, and 3) define cross-cutting technologies and collaborative opportunities.
2. **Accelerate manufacturing innovation by concurrently mature TRL, MRL and BcRL.** This addresses Grand Challenge #1 – current innovation process takes too long, costs too much and the impact is too random.

It is clear that the current innovation value chain is neither efficient nor effective. The current process going from lab research to marketable products is essentially “a random walk” with little guidance. Concurrent maturation of TRL, MRL and BcRL offers the following clear benefits:

a) a common language and a measurement of costs, risks and schedules,

b) a framework guiding GTMI-industry discussions and assessing opportunities,

c) a basis for regular progress reviews,

d) a different mind-set, focusing on exemplars, products, requirements, production environments, market pull, as opposed to “here is a new technology and find a place to plug it in,”

e) a process to catalyze alignment, foster trust and build an innovation culture.

3. **Engage Georgia Tech, state, national and global partners in advanced manufacturing to foster and sustain manufacturing innovation ecosystems.** This addresses Grand Challenge #2 – invent here, build here in the United States.

To effectively address the second grand challenge of “discover here, build here,” a different set of capabilities is required. To ensure that a new technology or product can survive once it has reached maturity and entered the marketplace, it requires a manufacturing ecosystem, or industrial commons. An ideal industrial commons provides a cluster of localized, interdependent businesses, which grow symbiotically and offer design, production, distribution, workforce, infrastructure, and investment capabilities to help all businesses in the same ecosystem thrive.

This is where the ecosystem readiness levels (ERL) comes into play. ERL measures the maturity a manufacturing innovation system relative to a specific technology. It is important to note, however, that unlike other readiness level tools, the ecosystem readiness level (ERL) does not remain constant once it reaches a certain level. A manufacturing ecosystem can ebb and flow like any living ecosystem. If certain pillars of sustainability begin to deteriorate, so does the ecosystem. That is why constant monitoring and upkeep is important in maintaining an existing ecosystem.

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8 TRL, MRL, BcRL are further defined and discussed in Appendix II.
"The 2013 Global Manufacturing Competitiveness Index," published by McKinsey and Council on Competitiveness, provides a good framework for assessing the readiness of a region. GTMI will utilize the following set of measurements in determining ERL:

- Talent to drive innovation
- Economic, trade, financial and tax system
- Cost and availability of labor
- Cost and availability of materials
- Supplier networks (covered in MRL)
- Legal and regulatory system
- Infrastructure
- Energy cost and policies
- Healthcare system
- Government investments in R&D, manufacturing and innovation
- Quality of life.

GTMI follows the principles outlined below in implementing its ERL strategy:

a) Develop and apply ERL in conjunction with TRL, MRL and BcRL;
b) Engage faculty and research staff in all six colleges, GTRI, IRIs, and EI via a dynamic network structure as opposed to a governance hierarchy;
c) Early and aggressive engagement of SMEs that support original equipment manufacturers (OEMs) through Georgia and the national MEP;
d) Work closely with state partners, including QuickStart, the Technical College System of Georgia, Georgia Centers of Innovation, Advanced Technology Development Center, Georgia Department of Economic Development, chambers of commerce, and transportation infrastructure agencies.
e) Develop partnerships with national leaders in advanced manufacturing:
   a. Industry, government and academic units
   b. Not-for-profit organizations and consortia such as the Georgia Automotive Manufacturers Association, National Center of Manufacturing Science, South Carolina Research Authority, etc.
   c. Professional societies like the Society of Manufacturing Engineers and Institute of Industrial Engineers

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d. Think tanks, including the Information Technology and Innovation Foundation and Council on Competitiveness

e. Workforce development organizations such as the Society of Manufacturing Engineers, Technical College System of Georgia, and QuickStart

f. National Academies

g. Best-in-class foreign organizations, e.g., Fraunhofer Institutes and Catapult (UK).
Plans

In its March 2012 strategic retreat, GTMI stakeholders created several major tasks and milestones to advance GTMI mission and implement GTMI strategy. Tasks 1-3 have been completed. Tasks 4 and 5 are still on-going:

1. perform an organization audit and create a new organizational structure\textsuperscript{10},
2. create an External Advisory Board\textsuperscript{11} (EAB) and a Faculty Advisory Committee\textsuperscript{12} (FAC),
3. initiate an Industry Partnership Program\textsuperscript{13}, or IPP, and hold an annual IPP Symposium,
4. Examine GTMI’s role and unique value propositions to its client base including faculty, administration and external customers,
5. Conduct a series of workshops and meetings to promote the xRL model.

\textsuperscript{10} The current GTMI organizational chart is in Appendix III.
\textsuperscript{11} The GTMI EAB By-law is in Appendix IV.
\textsuperscript{12} A discussion (draft) of GTMI FAC is in Appendix V.
\textsuperscript{13} IPP pamphlet is in Appendix VI.
Appendix I: Value Propositions of Georgia Tech Interdisciplinary Research Institutes (IRIs)

GTMI, as a member of Georgia Tech’s IRIs, offers a unique set of value propositions which are not provided by other GT research labs, centers, schools or colleges.

1. Brand management
   a. Vision
   b. Communications, marketing, media relations
   c. Messaging

2. Integration, synergy and collaboration
   a. Create a GT community
   b. Foster collaboration
   c. Seed inter-center, inter-school, inter-college, inter-university research ideas and programs
      i. In the confluences of disciplines
      ii. Transformative potential
      iii. Establish and promote through leadership
      iv. Manufacturing enterprise perspective
      v. Focused on accelerated translation
      vi. Integrated research and education
   d. Facilitate large-scaled programs and proposals
   e. Integrate research, education and workforce development

3. Services to faculty
   a. Human resources
   b. Information technology
   c. Financial management
   d. Facilities
   e. Technical supports

4. Infrastructure and core facilities

5. Translational agent
   a. The missing Bell Labs
   b. Crossing the valley of death
Appendix II: TRL, MRL and BcRL

TRL: TECHNOLOGY READINESS LEVEL
Technology readiness level (TRL) is a method of classifying the maturity of a basic technology for use in a product or process. TRL defines a set of readiness levels from 1 to 9 that provide an efficient way of communicating a technology’s current state along its development spectrum. A rating of 1 indicates that the technology is in a nascent state, just beyond the discovery phase. A rating of 9 indicates the technology is being used successfully in operations.

TRL was developed by the National Aeronautics and Space Administration (NASA) in the 1980s and is used by several large agencies throughout the world. Fortunately, most implementations make use of the 1 to 9 rating scale, but the meaning of the ratings can vary based upon the primary mission of the user: NASA and the Department of Defense (DoD) are two large users of TRL.

xRL makes use of TRL as one component of the overall readiness of a technology. Since TRL is well established and mature, xRL makes use of TRL without change. Currently, xRL makes use of the DoD readiness level definitions, but xRL may expand to use additional readiness level definitions to address various intents.

MRL: MANUFACTURING READINESS LEVEL
Manufacturing Readiness Level (MRL) is another established measure of overall readiness of a basic technology. As the name implies, it provides a way to communicate the readiness of a technology for use in a manufactured product or in a manufacturing process. It was initially developed by the DoD to improve the quality of procuring systems by the government. Specifics about MRL can be found in the “Manufacturing Readiness Level Deskbook.”

Whereas, TRL defines a single readiness level of a technology, MRL makes use of threads and sub-threads to provide a more extensive view of the readiness. Threads address nine manufacturing risk areas and consist of: Technology and the Industrial Base, Design, Cost and Funding, Materials, Process Capability and Control, Quality Management, Workforce, Facilities, and Management. Each thread is further divided into sub-threads that provide additional robustness and completeness to the analysis. MRL also defines a set of guiding/exit questions that are used to determine the readiness level of each sub-thread. The guiding questions are of great help to the users of MRL because they provide a systematic method of determining the current state and provide semantics about the readiness definitions. xRL makes use of MRL without
APPENDIX II: TRL, MRL AND BCRL

change to determine the manufacturing readiness of a technology within the xRL framework due to MRL’s active user community and expanding use.

MRL provides a more robust view of readiness than TRL because MRL studies 22 topic areas versus a single TRL classification. This robustness requires additional analysis and is more challenging to communicate. Since xRL combines multiple readiness frameworks into an encompassing analysis, the challenges associated with MRL will be exacerbated in xRL’s larger context. So xRL must be developed such that it can be applied without overtaxing resources and the results can be presented in a way that is easily interpreted by the intended audience.

BCRL: BUSINESS CASE READINESS LEVEL
To bridge the gap between innovation development and technology insertion, it is critical to incorporate Business Case Readiness Levels (BcRL) and Ecosystem Readiness Levels (ERL) into the process. Although very effective tools, TRL and MRL are not sufficient to guarantee successful and rapid insertion of a new technology. Neither has gained such broad-based acceptance as Six Sigma – a doctrine that has gained tremendous popularity worldwide in manufacturing, services and the public sector.

The reason for Six Sigma’s popularity is that it offers a clear focus on achieving measurable and quantifiable financial returns by determining “product cost,” the metric of choice for C-suite decision makers. Corporate executives can clearly see that when the quality level rises from Four Sigma to Five Sigma, the defects per million produced drop from 6,210 to 233. When the quality level reaches Six Sigma, another 230 defects per million are eliminated. Decision makers prefer bottom line numbers, and Six Sigma readily offers this data where TRL and MRL do not.

As a companion measure to TRL and MRL, BcRL captures the “financial” or “business” reasoning for launching a new technology or manufacturing project. The intent of BcRL is to methodically build a business case as the technology matures to shorten the time to market. It equips an integrated product and process design (IPPD) team with a disciplined maturation and evaluation process to bring the technology to market.

Unfortunately, most technology projects ignore the importance of their business case until late in the development process. As a result, there is not enough market pull to justify the new technology insertion because associated benefits and risks have not been studied and articulated.
For this reason, it is critical to develop technology, manufacturing and business case readiness simultaneously. The IPPD effort was a significant step in the right direction. However, maturing technology and manufacturing concurrently without building a business case does not guarantee successful implementation of the new technology or manufacturing project. In other words, without the prospect of a solid financial return, it is difficult to push a new technology into the marketplace, regardless of its level of innovation.

To build the business case, BcRL determines the technology readiness for market transition (technology push), the targeted unmet needs (market pull), the product insertion timeline (technology roadmap), a market capture strategy, and the financial benefits to the company. BcRL is compatible with TRL and MRL because it is organized at nine readiness levels, as shown in Figure 3. The critical phases are BcRL 3-7, where the technology development reaches a tipping point, and company executives are convinced of the potential business value of the new technology.

Since the focus is primarily on building a business case in the BcRL 3-7 space, each exemplar selected for a business case shall address “as risk” properties that are applied to real-world products in a representative environment. For example, a composite truck suspension link exemplar would be expected to have operating tensile properties in excess of 60 KSI and to operate in both wet and sandy environments between temperatures of -15°C to +55°C. These properties and environments are typical of commercial truck service throughout the world.

BcRL is meant to evaluate technology starting at a TRL of 2 or 3 and ending at the tipping point, at TRL 6 or 7. This tipping point corresponds to BcRL 6 or 7, where the technical concept initially developed at the lab is transitioned to initial market insertion. A tipping point may be characterized by a commercial success during test market evaluation.

The overarching objective of BcRL is to transition a technology from an academic or industry lab to market in a timely fashion so that product insertion immediately results in significant market success for the company. An additional benefit is when the academic institution starts to receive a positive cash flow and continuing royalty payments from the transition of its intellectual property. Ultimately, BcRL is a win-win solution for all engaged parties. Combined with TRL and MRL, the triad addresses the first grand challenge of ensuring rapid innovation and seamless transition from lab to pilot to production.
## Business Case Readiness Level

<table>
<thead>
<tr>
<th>Phase</th>
<th>BcRL</th>
<th>Readiness Level Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 3: Reaching the “Tipping Point” and on to Full Scale Market Insertion</td>
<td>9</td>
<td>Full Rate Production into National Markets – Future Product Improvements Planned</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Full Rate Production into Local Market – Confirmation of Financial Metrics Estimate</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Product Insertion into one Target Market – Positive Market Focus Group Response</td>
</tr>
<tr>
<td>Phase 2: Bridging the “Missing Middle”</td>
<td>6</td>
<td>Market Ready Research Prototype Vetted to Outside Entity and Key Customers</td>
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<td>Research Concept/Target Markets Presented to Industrial Partners – Fit to Strategic Plan Goals</td>
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<td>Research Concept Vetted to Outside Entity (ADTC, Incubator Board, etc.) for Review</td>
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<td>University Review and Validation of Potential Research Concept Marketing Insertion</td>
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<td>Research Concept Proven in Laboratory – PI Defines Usage of Potential Market Value</td>
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Figure 3. Nine Levels of Business Case Readiness Maturity
Appendix III: GTMI Organizational Chart
Appendix IV: GTMI External Advisory Board By-Laws

BYLAWS of the
Georgia Tech Manufacturing Institute
EXTERNAL ADVISORY BOARD

PREAMBLE
There is hereby created, adopted, and approved the following Bylaws for the Georgia Tech Manufacturing Institute (GTMI), External Advisory Board.

ARTICLE I
Name and Purposes
Section 1. Name. The name of this organization shall be the GEORGIA TECH MANUFACTURING INSTITUTE EXTERNAL ADVISORY BOARD hereinafter referred to in these Bylaws as the "EAB".

Section 2. Purposes. The purposes of the EAB are to act as an advisory body for the GEORGIA TECH MANUFACTURING INSTITUTE hereinafter referred to as the "GTMI"; to advise the leadership team on programs and policies; to advise the Director, Principal Investigators and researchers on project selection, policies and procedures; to encourage resource development through advocacy for state and federal funding; to help advise the education, outreach and research programs of GTMI; to assist in publicity and public relations and other matters relevant to the operation and strategy of the GTMI; engage industry in mutual value opportunities.

ARTICLE II
Organization and Administration
Section 1. Number. The EAB shall consist of between 12 and 18 regular members as determined by the Board Chairman of the EAB and ex-officio members as deemed appropriate. This number may be increased on a temporary basis when new members are added in advance of the expiration of other members' terms. Included among the members shall be representatives of a diverse representation of manufacturing sectors.

Section 2. Manner of Selection and Term of Office. (a) Candidates for membership on the EAB shall be nominated by EAB members or the Director, GTMI and serve terms of up to three (3) years. (b) The terms of office of those constituting the regular members of the EAB shall expire on June 30 of successive years, with the goal being that the terms of one third of the members, in general, expire each year. An EAB member may not serve more than two (2) consecutive terms, with exceptions requiring approval of the full EAB. EAB members who serve as Chair may have their terms extended to cover these periods of service if they commence with or extend beyond the two (2) consecutive terms of normal service. Past Chairs will serve as Chairs Emeriti and are invited to attend EAB meetings after their terms of office expire.

Section 3. Vacancies. In the event that a regular member of the EAB ceases to serve for any reason prior to the end of his/her term, a successor to serve the unexpired term of such member may be appointed upon the recommendation of the Board Chair or Director, GTMI.

Section 4. Meetings. The EAB shall hold at least two (2) regular meetings each calendar year, the
APPENDIX IV: GTMI EXTERNAL ADVISORY BOARD BY-LAWS

data, time, and place of which shall be designated by the Chair. Unless otherwise designated by the Chair, meetings shall be held on the Georgia Tech campus in Atlanta, Georgia. Written notice of each regular meeting shall be given to each member of the EAB at least thirty (30) days prior to the meeting. The Chair may call a special meeting of the EAB at any time. The Chair shall be responsible for issuing notices of all regular and special meetings. Any member of the EAB may participate in such meetings via conference call, which participation shall be deemed presence at such meeting for all purposes. Substitutes or surrogate participation is not permitted.

Section 5. Quorum. A quorum shall consist of one-half of the number of regular members of the EAB. Whenever a quorum is present, a majority vote of those members of the Board constituting the quorum shall determine all actions.

Section 6. Minutes. Minutes of meetings of the EAB shall be recorded at all meetings by a representative of GTMI as designated by the Chair. As soon as practical after the close of the meeting, copies of the minutes shall be distributed to all EAB members.

ARTICLE III
Presiding Officer

The presiding officer shall be the Chair of the EAB, hereinafter referred to as "Chair." The Chair shall be selected by the EAB and shall serve for a period of two (2) years. In the event the Chair is not able to preside, a member of the EAB shall be elected from among the EAB members.

ARTICLE IV
Amendments

These Bylaws may be amended at any regular or special meeting of the EAB, provided that the proposed amendment has been furnished to the EAB in writing at least 10 days prior to such meeting.

Appendix – Expectations for Members of the GTMI EAB

To meet the stated purposes of GTMI and to advance the purposes of manufacturing excellence and research, the expectations of EAB members are to:

1) Attend the two regular meetings of the EAB each calendar year, or inform the Chair for the occasional meeting when attendance is not possible;

2) Be an active participant in activities held between the regular meetings serving as a strong advocate for the GTMI;

3) Read materials prepared in advance of meetings and come prepared to engage in discussions and
4) Engage the Director in charting the mission, strategy and priorities of the GTMI.

5) Engage the Director regarding strategic focus on importance to users and implementability.

6) Suggest candidates for membership on the EAB.

Adopted 15 May 2013

Board Chair [Signature]
APPENDIX V: A DISCUSSION (DRAFT) OF GTMI FACULTY ADVISORY COMMITTEE

Appendix V: A Discussion (draft) of GTMI Faculty Advisory Committee

MISSION: The mission of the GTMI Faculty Advisory Committee (FAC) is to advise and assist the Executive Director of the Georgia Tech Manufacturing Institute in surveying and accelerating innovations, while identifying and addressing grand manufacturing enterprise challenges that have the potential to enhance our nation’s wealth, security, and competitiveness.

GUIDING PRINCIPLES: Faculty at the Georgia Institute of Technology are known for producing meaningful, ethical, cutting-edge research within a supportive, intellectually free environment. Many are ideally suited to advise, assist, support, and advocate the education, research, and technology transfer activities associated within GTMI. Hence, the service of those selected to the FAC is not to “rubber stamp” what already exists, but to offer suggestions for improvements that will help the program grow and expand. Key to success is commitment on the part of the committee members as well as participating administrators.

PURPOSE: The GTMI Faculty Advisory Committee (FAC) shall advise the Executive Director on matters of policy and thought in support of the research, development and commercialization of manufacturing-related technologies. The FAC shall provide guidance on the selection of faculty that request GTMI membership, offer advice on the management of GTMI space and resources, and serve as a forum to discuss manufacturing-related issues at the Georgia Institute of Technology. The committee is a direct two-way communication channel that faculty who choose to support GTMI and administration can use to convey issues and receive information about manufacturing-related concerns. Facilitating communication, engaging members of the research community, and addressing policies that accelerate innovations and address grand manufacturing enterprise challenges are key issues for this committee.

LEADERSHIP: The FAC shall operate as a committee of tenured faculty members with a Chair selected from its membership, who will work with the GTMI Executive Director in establishing an agenda. To ensure continuity, members in leadership roles will serve three successive years as members. At the end of the academic year, a first-year member of the committee will be elected Chair-Elect and will serve in that role during his or her second year on the committee. The Chair-Elect will assume the role of Chair in the third year of service on the committee and will continue as a non-voting member (Past Chair) the following year. The GTMI Executive Director and Past FAC Chair shall serve as ex-officio members.

COMPOSITION: This committee shall consist of 12 voting members, who are tenured faculty and qualified as members of GTMI. The twelve shall include four senior and or emeritus representatives known for their substantial contributions to Georgia Tech and GTMI, four internationally renowned faculty from diverse departments within the Georgia Institute of Technology, and four residents within GTMI facilities. These members shall serve staggered non-succeeding three-year terms. If elected to the FAC Leadership, an additional year on the FAC as Past Chair is expected.

GTMI MEMBERSHIP: To be a GTMI faculty member, eligible to serve on the FAC, one must share and embrace the idea of conducting collaborative research that encourages stakeholders of the regional manufacturing ecosystem and supports the concept of discover here, build here.
Appendix VI: GTMI Industry Partners Program

Why Partner with Georgia Tech?

Georgia Tech is recognized as one of the world's top research universities, but not only in the United States. One of the nation's 25 top research institutions, Georgia Tech is also known for its research programs in Manufacturing, Technology, and Logistics. Our primary goal is to translate our competitive advantage into real-world solutions that can be integrated into the global marketplace.

* Since 1991, Georgia Tech has invested more than $1.5 billion in research and development, allowing us to compete at the highest levels in the world.
* Our faculty and staff are experts in their fields, working on projects that span a wide range of disciplines.

For more information on the Georgia Tech Manufacturing Institute Industry Partners Program, please contact:

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Suppose you are in charge of...

A company that needs help developing an efficient manufacturing process or a new product.

A process that relies on production quality to stay competitive.

A company that is looking for a way to differentiate itself in the market.

A process that relies on production efficiency to stay competitive.

A process that relies on production quality to stay competitive.

Membership

Benefits

* Our Industry Partners Program is structured to help manufacturer and process engineers improve the value of their processes, and enable innovation through awareness and relationships. Membership in the GTMI Industry Partners Program provides you with access to:
  * Georgia Tech Faculty and Student Talent
  * Full access to Georgia Tech faculty in materials, process, and design
  * Research and development opportunities across the manufacturing spectrum
  * Georgia Tech's world-renowned engineering programs

Research & Development Infrastructure

* Visits to research facilities
* Access to Georgia Tech's facilities
* Mentorship opportunities
* Graduate research opportunities

Networking

* Access to a network of other industry partners
* Build awareness of your company to obtain one of the best opportunities available

Information and Education

* Opportunities to network with other industry partners
* Access to the latest research and resources

Program Requirements

* Membership in the industry partners program is open to all companies, regardless of size.

Leverage

* Membership in the GTMI Industry Partners Program is open to all companies, regardless of size.

For more information, please contact:

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Appendix VII: Annotated History of the Manufacturing Research Center

By Steven Danyluk, 2013

The genesis of the Manufacturing Research Center (MARC) was initiated in 1988 when the administration sought and received support from the State of Georgia and industrial partners for a dedicated research center to be housed in a new building at the north end of the campus. Funding was committed by the then Governor Joe Frank Harris and continued under Governor Zell Miller, the Institute under president John Crecine and four companies: Motorola, IBM, AT&T, FORD and the Department of Defense Manufacturing Technology program who each committed $1M each over a five year period i.e. $200,00 per year each. To spur participation, the overhead rate for company support was reduced and additional funding was provided by the Institute. The focus and emphasis of this group was in electronics manufacturing.

The first Interim Director was Dr. Michael Thomas, the Chair of the Industrial and Systems Engineering School, who subsequently became provost, and the building construction completed and dedicated in 1991. ME faculty took over residence of approximately 40 percent of the building shortly after the dedication with the remaining space occupied by the faculty of the school of Industrial and Systems Engineering. A permanent Director, Dr. Michael Kelly, was hired in 1991.

MARC had a permanent staff of 14 individuals including a Facilities Manager, a Research Director, Public Relations and IT support. A technician and Admin support rounded out the staff.

One of the first major organized activities to occupy MARC was the Materials Handling Center, an NSF-supported Industry-University Cooperative Research Center, headed by John White, who subsequently became dean of the College of Engineering and is currently the president of the University of South Carolina. Another major activity addressed food processing and was led by the Georgia Tech Research Institute.

Steven Danyluk (Morris M. Bryan, Jr. Chair in Mechanical Engineering for Advanced Manufacturing Systems) assumed Directorship of the Center in 1994 with two Associate Directors: Leon McGinnis (Gwaltney Chair in the School of Industrial and Systems Engineering) and Edward Kamen (Hightower Chair in the School of Electrical and Computer Engineering). This leadership team worked closely with the school chairs and expanded the focus of MARC to include precision machining, rapid prototyping, electronic board assembly, sustainability, and digital design. The center operated by working closely with a lead (senior) faculty member in each of these areas, hiring a research professional for each of these areas and providing funds to sustain the activity. New research ideas were reviewed periodically and funding was provided to seed the most promising areas of research. The admin staff, facilities manager, IT support and technician provided the support of this activity. Over the years, MARC has expanded to include offices in the Management building in Tech Square, and at the MRDC, and the Associate Directors included faculty from ME, ECE and ISyE.
Contact Information

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<thead>
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<th>DR. SHREYES MELKOTE</th>
<th>TINA GULDBERG</th>
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<tr>
<td>EXECUTIVE DIRECTOR</td>
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