Executive Summary
Small- to mid-sized manufacturing enterprises (SMMEs), both defense and commercial, face unique obstacles in the marketplace, which is why systems of innovation must be established through workplace culture and leadership that ensure success. This report serves as a roadmap of multiple systems across defense and commercial enterprises, from Original Equipment Manufacturers (OEMs) to small startups. The roadmap was constructed by researching OEM's implementation of well-known lean principles and concepts, entrepreneur's product commercialization processes, and innovation processes that some small and medium-sized enterprises and support organizations have adopted. The goal is to outline best-practice models that small- and medium-sized manufacturing enterprises (SMMEs) interested in product development and commercialization growth may employ.

Introduction
In an effort to better understand how both defense and commercial manufacturers may add value-added innovation to their products and services, a breakdown of innovation models developed and used by original equipment manufacturers (OEMs), budding entrepreneurs, as well as select small and midsized manufacturing firms was conducted to determine their characteristics. Defense and commercial SMMEs can learn from the innovation processes of large OEMs, entrepreneurs and even other growth-oriented small- and medium-sized practices. Each stage of business development has similarities and differences that can be applied.

Since World War II, a good share of business innovation processes has been based on the linear model of innovation (Figure 1). In its simplest form, this model charts the innovation process from new scientific research, through segmented stages of product development, production, and commercialization, and terminates with the successful sale of new products, processes, and services. The model is built upon strong basic scientific research as a way to maintain leadership in high-technology markets.

Figure 1. DoD Linear Model of Innovation

The Department of Defense (DOD) further embedded the linear model into its research and development (R&D) priorities. In its current form, the DOD research, development, test and evaluation model breaks the innovation process into seven stages:

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1. Research: New concepts are developed through laboratory research.
2. Exploratory development: Promising research results are applied to preliminary laboratory devices.
3. Advanced development: Technologies are demonstrated in representative systems and prototypes are developed.
4. Demonstration and validation: Technologies that meet an articulated operational need are demonstrated and validated.
5. Engineering and manufacturing development: The product/system incorporating the new technology is redesigned for manufacturing.
6. RDT&E management support: Provides overhead and management funds for all RDT&E activities.
7. Operational system support: Systems in production or already fielded are improved and upgraded through the incorporation of new technology.

Projects move sequentially through the categories, from basic research through development and manufacturing, as the technology matures and is applied to new military systems. Because DOD funding dominated federal R&D expenditures throughout the postwar period and drove much of the U.S. research agenda, these categories have influenced commercial product development and commercialization innovation models in the United States.

Original Equipment Manufacturers
Original Equipment Manufacturers (OEMs) have focused on organizing their product development activities as a linear progression from research lab to marketing, while tweaking the methods to suit the company’s management practices. The OEMs analyzed in this paper – Toyota, Honda, and Goodyear – have replaced this model, to a large degree, by concurrent forms of product development in which responsibility for new product development is given to a project team consisting of representatives from the research, development, manufacturing, and marketing divisions. For large Original Equipment Manufacturers (OEMs), innovation cycles tend to be incorporated throughout the entire enterprise, but particularly within the research and development phase. Emphasis on Lean and Six Sigma principles is vital for the success of the innovation process; typically, OEMs use in-house innovation processes and models that are distributed vertically throughout the entire supply chain. While disruptive innovation is of course welcome, OEMs appear to specialize in creating incremental innovative progress every year by releasing new models of the same product.

Lean Driven Innovation at Goodyear Tire & Rubber Company
Founded in 1898 in Akron, Ohio, as a tire and vulcanized rubber manufacturer, Goodyear implements Lean manufacturing specifically designed to streamline the R&D process. In order to stay on top of emerging developments in industries such as Formula One racing, aircraft, and farming machinery, Norbert Majerus explains in his book *Lean Driven Innovation* that 30% of research and development (R&D) practices are spent researching new ideas and 70% to develop new products for these industries. According to Majerus, complaints that Lean models do not coincide with creativity is simply not true. Traditionally, Lean excels at creating incremental innovation. But it fails, however, to provide disruptive game changing products. In order to make Lean driven innovation successful, there must be a strong connection between the product development program and a winning innovation culture (Figure 2). For Goodyear, this innovation culture was fostered using two lean principles and directing them towards R&D:

- Reinvest the gains from waste elimination back into R&D
- Focus on creating customer value in product to development during R&D
These seem like basic principles but are key to making innovation processes work within R&D. Goodyear came out with completely new products using this strategy, making up for the loss of some of its largest serving industries over the decades. To solidify and put these principles into practice, a company-wide culture of value sharing, open communication, and good training among administration, research and development and manufacturing departments must be maintained. Norbert Majerus explains that innovation done well at Goodyear requires leaders who believe in the mission, people who “rock the boat,” and people who can steady it. This balance of idea creation and product workshop using Lean tools is what makes innovation at Goodyear work.

**Staying Ahead of the Market at Honda**

Founded in 1959 to manufacture automobiles, aircraft, motorcycles and power equipment, one of Honda Motor Company’s achievements in innovation was being the first Japanese auto company to create a luxury brand, Acura. Honda uses the Sigmoid curve (Figure 3) to time its innovation processes. The Sigmoid curve illustrates the life of a product cycle, beginning in a slight downward slump with inception of the idea and then rising rapidly during growth and maturity phases, while eventually declining shortly after the product reaches the market. A single multinational cross-departmental team of innovation experts is in charge of studying product life cycles and creating new ideas before the next product is released. This approach to innovation sets Honda apart because they do not experience the additional inefficiency or expense that comes from the traditional approach, which is to create many different ideas at the large end of the funnel and wait for the best idea to exit the workshop process.

This also means that Honda’s innovation is primarily incremental, honing new products to the next level of perfection. However, new market-disrupting ideas do eventually emerge from this process. Like Goodyear, Honda uses hardline traditional Lean approaches throughout its entire business model. But their biggest contrast is in timing. Honda’s innovation model is much quicker - staying ahead of the market, being predictive, rather than taking cues from emerging technologies in the industries that they serve. Honda *creates* the emerging technologies themselves, spending about 5% of their total
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revenue investing in entirely new ventures. This difference between being proactive and reactionary is a cultural one.

At Honda, there is a certain emphasis placed upon respecting individualism. The leadership culture at Honda is viewed from the perspective of the individual, their unique talents, and capabilities. When it comes to innovation, the individual is treated as a wellspring of knowledge and decision making on which the total group’s performance depends. This creates an atmosphere of friendly competition between designers that is vital to staying ahead of the market curve.

_Pervasive Innovation Culture at Multinational Toyota_

Toyota Motor Company, founded in 1937, specializes in creating affordable automobiles and hybrid electric vehicles. While Honda crafted an innovation leadership culture around individualism, Toyota is just the opposite. The mission at Toyota is so pervasive that it has been coined the “Toyota Way.” This mission is to continuously contribute to the growth of the economy in which the factory is located and the wellbeing of its employees; resulting in the personal growth and satisfaction of the individual. This big picture approach is what makes Toyota’s innovation model so unique.

From the beginning, Toyota’s fruitful partnerships with suppliers are what has led to success. These supplier partnerships led to the invention of the “Toyota Production System,” or TPS, which triggered a global shift in supply chain philosophy over the past decade. TPS is an extremely detailed, company-wide process that applies familiar Lean and Six Sigma principles (called kaizen, just-in-time, one-piece flow, jidoka, and heijunka) to the entire production process, including innovation (See Figure 4). TPS is designed to reduce and eliminate waste, optimize efficiency, and deliver custom products quicker than ever before, essentially placing the customer first. All of the employees at Toyota, from engineering, sales, service and parts, accounting, and human resources are trained on the principles of TPS. This creates an immediate connection between Toyota’s customers and its employees. The primary element to Toyota’s success is a big-picture, holistic implementation of the value that innovation provides to the customer. Innovation at Toyota doesn’t have to be simply about the product, but instead can be about the process itself.

_**Key Takeaways from OEMs for SMMEs:**_
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- Lean, Six Sigma, and other waste reducing product management techniques are vital to the success of producing innovation. These principles can be incorporated flexibly into the OEMs, but their effectiveness with SMMEs will depend upon the existing management structure of the company.
  - SMMEs should find ways to utilize and implement Lean into their operations early.
  - Make those values unique to the business model and train every single employee on those principles.
- Create an atmosphere of willing adherence to the rules and respect for the process, ensure your managers and corporate leaders know how it works to address compliance issues.
- Product innovation and commercialization entities such as the Ohio State Center for Design and Manufacturing Excellence can benefit SMMEs by adapting OEM practices to SMME needs; a set of translational, applied research approaches that adapts these techniques will help rise the tide of manufacturing innovation.

Entrepreneurial Ecosystems and Innovation

The entrepreneurial ecosystem is an entirely unique system of innovation that differs greatly from the processes that OEMs utilize (see Figure 4). Over the course of several months and multiple rounds of interviews with Northeast Ohio entrepreneurs, higher education institutions, business incubators, and accelerators, we learned that startups rely closely on the support of an interconnected business ecosystems. This elaborate network of support services, funding pools, and training resources has been partially sustained and fueled by higher education centers, economic development agencies, led by Lorain County Community College’s (LCCC) Innovation Fund of Northeast Ohio (IF-NEO) and Great Lakes Innovation and Development Enterprise (GLIDE).

Figure 5 outlines the simultaneous bottom-up, top-down structure of the entrepreneurial support system of Ohio.

Key Differences between OEM and Entrepreneurial Innovation

Unlike OEMs, whose precisely honed processes focus on incremental innovation, startups primarily use out-of-house innovation techniques that are intended to be disruptive in nature. However, given the high failure rate and great risk associated with starting a new business, companies often fail before being able to take that idea to market. Once receiving support and financial resources during the early stages, an abysmally low number of market-disrupting products actually reach maturity. Small companies who do succeed in creating something truly unique and disruptive are often bought out by large, well-known manufacturers. Yet still, in many cases this is seen as success.

Figure 5. Entrepreneurial Support Ecosystem
Entrepreneurs are focusing on creating new, tech-based products. This complicates matters for SMMEs, since many new ideas coming out of the entrepreneurial business pool require less hard manufacturing and more software development. For instance, the prevalence of Industry 4.0 and Internet of Things (IoT) technology has led to a significantly greater amount of attention being given to products that are Internet capable. However, the cost of new IoT technologies for manufacturers is still prohibitive.

This leads to a gap between the products that entrepreneurs want to make and the resources available for them to do so. In addition to many services designed to financially sustain young startups, there is a complicated interplay of organizations that offer educational training and business support services as well. Each of the organizations that offer these services encourage innovation development using their own models.

**GLIDE – Pre-seed Innovation Center, Northeast Ohio**
Lorain County Community College’s Great Lakes Innovation and Development Enterprise assists entrepreneurs by giving them one-on-one coaching with faculty at the college in addition to access to campus facilities such as 3D printing and modeling. GLIDE encourages innovation through education, mentoring, and small-scale investment (Figure 5) and operates in conjunction with the Innovation Fund of Northeast Ohio to provide pre-seed funding in increments of $25,000 to $100,000. Only the most innovative ideas for product development are considered.

**JumpStart: Product Commercialization Incubator, Northeast Ohio**
Northeast Ohio has taken a micro-regional approach to innovation through organizations like JumpStart. To respond to the need for job and wealth creation in the Cleveland area, philanthropic leaders from communities across northeast Ohio formed public-private partnerships geared towards economic transformation. JumpStart operates towards the end of the entrepreneurial pipeline when businesses are ready to scale up. Innovation at JumpStart resides in the marketing process, training entrepreneurs on how to aggressively market their products.

**BioEnterprise – Product Commercialization Incubator, Northeast Ohio**
Similar in operations to JumpStart, BioEnterprise out of northeast Ohio is another business incubator that specifically helps entrepreneurs entering the medical technology field. BioEnterprise focuses on growing companies that are ready to scale up and have a concrete minimum viable product and business model. Innovation also focuses on late-stage business model development and the marketing phase.

**Key Takeaways from the Entrepreneurial Ecosystem for SMMEs**
- Innovation models operate differently in the entrepreneurial ecosystem when compared to OEM processes because their business models have not reached full maturity.
- The interconnectedness of the pipeline between higher education and state funding mechanisms is vital for the innovation processes of startups.
The biggest lesson for SMMEs to take from entrepreneurial ecosystems is to leverage the entire network of support providers available in a region.

Ohio State’s Center for Design and Manufacturing Excellence (CDME) and its Manufacturing Extension Partnership affiliate status offers the types of resources that can be made available to infuse entrepreneurial support into the SMME network.

Resources for SMMEs

Simply stated, large companies (OEMs) tell suppliers what to buy, not what to innovate. While this lowers risk, the bidding process does not incentivize increased product development and commercialization within the supply chain ranks. Models of innovation utilized by small- to mid-sized manufacturing enterprises (SMMEs) usually involve external innovation partners, whether MEPs or industry-focused groups, that are engaged as the company approaches different stages. These external resources evaluate whether the company is ready for innovation or growth in the initial steps of the relationship.

With circumstances that depend on product space, culture and technical expertise within the firm, No one generalizable model exists for SMMEs. Third-party innovation service providers usually pick models based on what is consistent and necessary to help companies succeed. One of the conditions for success is when service-oriented organizations have processes that connect the innovation models to a company’s specific situation, not through a one-size-fits-all model. Depending on the characteristics of a company, there are dramatically different types of innovation and barriers that must be assessed – this may take different shapes than OEM innovation models, due to the limited technical and human resources available.

Ohio Manufacturing Extension Partnerships

The Ohio Manufacturing Extension Partnership (MEP) includes CDME (Central and Southeast), the Center for Innovative Food Technology-CIFT (Northwest), FASTLANE (Southwest) Polymer Ohio (Central), MAGNET (Northeast) and TechSolve (South). The state MEP system run by the Ohio Developmental Services Agency works to consolidate innovation models across the State so that SMMEs can take better advantage of the resources available to them. The Manufacturing Extension Partnership is a federal level initiative sponsored by the U.S. Department of Commerce National Institute of Standards and Technology (NIST).

Ohio MEP affiliates, as with the national network, have utilized several different innovation models and product commercialization methods. For example, one of MAGNET’s programs, PRISM (Partnership for Regional Innovation Services to Manufacturers), was an innovation model that brought to the table private sector, public sector, and higher education institutions to create innovation strategies for manufacturers. Several years after its launch in 2013, the partnership was folded into central operations. The engineering innovation work has moved from more of a transactional enterprise with small and medium firms to a long-term relationship management approach with companies.

When OMI convened a panel of affiliate directors at the National MEP Summit in 2017, several outlined the models that they use most often when working on product innovation and development with client firms:
Stage-Gate Models
Nationwide, MEP affiliates have utilized a series of innovation models to serve SMMEs and their product development and commercialization needs. The Stage-Gate model operates in a similar capacity as the LCCC/GLIDE screening process where applicants begin with an innovative product idea. The key difference is that MEP’s stage gate process is tailored specifically to the size of the enterprise and the stage of product development, which can be seen in figure 7.

Stage-Gate deals with ideation in the initial stages—the five phases include scoping, building the business case, development, testing and validation and the project launch. Each of these gates focus on three main elements:

- **Inputs**: What the project manager and team deliver to the decision point. These deliverables are decided at the output of the previous gate, and are based on a standard menu of deliverables for each gate.
- **Criteria**: Questions or metrics on which the project is judged in order to determine a result (go/kill/hold/recycle) and make a prioritization decision.
- **Outputs**: Results of the gate review—a decision (go/kill/hold/recycle), along with an approved action plan for the next gate, and a list of deliverables and date for the next gate.

The emphasis on gates is to ensure that checks are in place to ensure quality of execution, business rationale and the development of an action plan.

**Eureka!Ranch – Product Commercialization Incubator, Southwest Ohio**
Historically, a number of affiliates within the NIST MEP system have become licensees of Eureka!Ranch, an innovation-centered business incubator out of Cincinnati, Ohio. The organization focuses on helping entrepreneurs, both small and large, develop market disruptive ideas at the earliest stages of business development. To do this, Eureka! Ranch offers System Driven Innovation through ideation consulting, training and certifications in business growth management that focus on creating a culture of service leadership and principles rather than a “recipe.” This approach to business management training revolving around system driven leadership has been coined “Innovation Engineering.” The goal for the training programs is to
establish a market-disrupting big idea and vetted business plan within 60 days. The training programs have been a way to get companies through the door to explore additional growth opportunities.

Doug Hall, founder of Eureka!Ranch, developed an innovation engineering system that claims to maintain the product development and commercialization process as a continuous cycle. Through Plan, Do, Study, Act, risks can be managed to mitigate market risks, or “death threats,” and lead to more productive innovation development through rapid prototyping.

Cultural Innovation Approaches
MEP affiliate directors also mentioned that sometimes, a customized approach that addresses the innovation culture is needed to work on a product being developed by a firm. Support systems used by SMMEs sometimes focus on the cultural aspect of innovation that was discussed previously in the section about OEMs. The cultural innovation model is geared towards smaller SMMEs rather than larger OEMs with well-developed in-house innovation standards and protocols. The difference is that with OEMs, different opportunities for innovation can occur simultaneously by multiple departments at a faster pace. With the cultural innovation model, innovation opportunities happen in a more linear fashion, but the opportunities are still the same. The social culture of the enterprise and timing of management decisions makes a great difference in how quickly innovation occurs and what is needed to populate the process with qualified individuals who have the skills needed to support the innovation process. The moving aspects of management decisions and training cycles can be seen in figure 9.

Center for Design and Manufacturing Excellence
Ohio State’s Center for Manufacturing and Design Excellence (CDME) is the central Ohio hub for entrepreneurs and has a mission to assist startups and manufacturing companies of all sizes with commercializing their products. CDME’s innovation model begins with exploring viability of the business through business validation, moves through R&D, introduction, growth, maturity, and decline phases, and terminates with end of service (see figure 10). Throughout the phases of product development and commercialization, design and marketing considerations are taken into account via in-house engineering staff and faculty technical expertise. CDME also utilizes the technical assets and expertise of engineering students to drive design and innovation processes.

Since engineering services are located in house, the center can quickly engage in agile tooling, prototyping and testing, new technology development, and process/product development and
improvement. The ability to bolt together a number of discrete projects with generalizable models for product development and process leads to improved competitiveness of firm.

Key takeaways of SMME models used by support organizations:
- A great majority of the models seem to broadly follow the StageGate approach of “define, discover, develop, deliver”
- Relationship development, training and tools to support small and medium enterprises is key, especially for long-term customers
- Faculty assistance can help with product development and commercialization training if a project manager is assigned to connect them with firms; this is a difficult nut to crack
- Bridging fundamental to applied research is important to develop SMME products that can be commercialized
- MEP-funded services allow SMMEs to buy down the cost of doing research

Conclusion
The goal of this summary document has been to help determine the innovation models that small- and medium-sized defense and commercial manufacturers can consider for improving their enterprise. The case studies on product innovation highlight OEMs, entrepreneurial networks and MEP-supported models – in short, models with structured processes that have innovation as a major component.

Using product development and commercialization work to discuss the need for early stage technology development funds for SMMs. How do universities take leadership in helping companies pursue product development and commercialization opportunities? Many university-affiliated innovation centers, whether associated with MEPs or not, have not been able to crack the nut at getting faculty members involved in applied innovation research.

One step advocated by OMI is to innovate with the larger goal of supporting OEMs by driving innovation to Tier 2 and beyond suppliers. The ultimate question is: how do you make for a faster supply chain of vertically innovative firms that also results in a reliable aggregation of innovation-driven firms?

For small- to mid-sized manufacturers, considerable time and effort must be allocated to applied research within the innovation cycle. This process, especially in evaluating new technology product and process applications, often requires considerable trial and error because
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Performance cannot be predicted with accurate models. Reducing time to market is crucial to bring new product to market, so firms must become efficient in all functions of product development and commercialization: research, design, development, manufacturing, and marketing.

What’s similar and what works across all of the models discussed is the conjunction of the product development process with the product cycle itself. Successful innovation occurs in the middle of this process, between developing the product and the next product cycle. The pace at which products are put onto the market should be quick. Lessons learned from OEMs show that a successful enterprise will take an idea to market quickly, while proactively researching ways to improve it in an iterative fashion. However, many smaller enterprises are risk averse, as a failure can greatly impact the bottom line. And even OEMs will admit that innovation and commercialization are the weakest of multiple priorities, including workforce skills, advanced materials and data analytics.

The primary issue facing SMMEs is quickness to market, coupled with obstacles to adopting and implementing innovation models early on in the business model. Product development should be streamlined from the beginning as soon as a minimum viable product is established. The key to helping SMMEs establish good innovation practices lies with implementing innovation principles early in the business model and creating a ubiquitous leadership culture that respects those principles and incentivizes every employee to creatively add value to the way the business runs. Essentially, SMMEs need support in structuring their business model from the ground up, and then sustaining it from the top down.

Innovation, the spark that fuels the economy ever forward, is at its best when a culture of service leadership and an intimate understanding of the production process is a deeply integrated part of the business model. Regardless of the size of the enterprise, a simple, cohesive, and holistic innovation model continually serves as the best tool that drives company success – particularly for a process as mechanized as manufacturing. Even more importantly, the more understandable the model is, the more quickly workers can be trained to quicken product cycles, spot discrepancies before they happen, adhere to safety practices, and ultimately have a better workplace experience.

With the variety of methods, models, and systems that have served as successful tools that inspire manufacturing innovation, picking a specific approach to product development and commercialization may prove confusing. Firms must be able to access reliable resources to help convert new science and technology discoveries into a proprietary advantage they can defend.
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in the marketplace. While firms can develop many of the requisite tools themselves, others often lie beyond their control. These needs can often be met through cooperative actions between firms, or between industry and government. That is where university product development and prototyping labs such as CDME as well as the resources of MEPs that are well versed in these practices can assist.

Building from the CDME EDA grant research, OMI’s next steps will be to undergo a deep analysis of specific case studies from the viewpoint of SMMEs that have successfully engaged in product development and commercialization practices using OEM and entrepreneurial practices. Those that have charted their own distinct paths will also be included. Of special interest are those that have been customers of universities and support organizations such as the MEP affiliates in managing disruptive technologies. Interviewing SMMEs should unveil the specific leadership approaches universities can take to help firms successfully pursue product development and commercialization opportunities.

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