Roadmap to Guide Construction Safety Research Commercialization

A.M. Costin [a], J. Felkl [b], O. Golovina [c], and J. Teizer [d]

[a,d] School of Civil and Environmental Engineering, Georgia Institute of Technology, USA
[b] Cockrell School of Engineering, The University of Texas at Austin, USA
[c] Moscow State University of Civil Engineering, Russia
E-mail: aaron.costin@gatech.edu, j.felkl@utexas.edu, teizer@gatech.edu

Abstract -
There is a great difficulty for students or faculty to commercialize their novel idea or invention from the university laboratory. Traditionally, university research has not been intended for commercializing while still within the university. However, recent trends create a paradigm shift for researchers to include a business mind-set to establish technology commercialization objectives. Still, there are major gaps to the widespread adoption of the practice of commercializing university research. There has been great success in research and technologies for construction safety research, including hazard detection and monitoring, resource monitoring, preventative practices, and Occupational Safety and Health Administration (OSHA) rule checking. However, there is an overall lack of commercialization of construction safety research which prevents the widespread adoption of such safety inventions in industry. The purpose of this paper is to develop a roadmap, integrating research design and known business techniques, for the commercialization of construction safety technology research. Significantly, this paper will help guide students and faculty on a path to apply leading safety research to the construction industry, potentially saving money and lives.

Keywords: Commercialization; Construction Safety; Entrepreneurship; Innovation; Research to Product; Technology Transfer.

1 Introduction

University research advances scientific discovery and generates a large amount of technological knowledge. Since the Bayh-Dole Act (1980), university patenting and licensing has significantly increased as a result of several trends. Yet, because university technologies tend to be very-early stage, only a relatively small fraction of university-generated knowledge results in commercially successful products. Unlike in industry where specific research is in the core expertise of the business, in case of universities, most new technology application will lie outside of university's core expertise (teaching and research).

From the academic perspective, universities fulfil three missions: research, teaching, and service. Some argue that supporting entrepreneurship and new technology commercialization falls under the public-service mission and possible return on public research and development (R&D) money invested in fundamental research. However, a large challenge to this endeavour and fulfilment is the well-defined Innovation Gap [1, 2] at the university between the technical knowledge creation and a successful product in the marketplace.

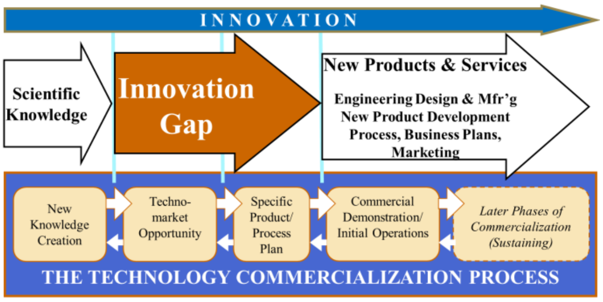

Figure 1. The Innovation Gap between scientific knowledge and product development (after [1,2]).

In the area of construction health and safety research, there are many new exciting developments, including personal fall protection guardrail equipment [3], a Building Information Modelling (BIM) Occupational Safety and Health Administration (OSHA) rule-based safety checker [4], real-time pro-active personal protective equipment [5], and other advanced personal protection equipment or computational methods for construction health and safety. Historically, however, very few have been successfully commercialized. This can be in part attributed to lack of knowledge among researchers and the challenges of licensing and/or creating a startup. The goal of this work is to help shed light and provide a structure and a guide on the commercialization process. It includes resources available, and several investigated case studies to provide a practical reference for Construction students, faculty, and researchers interested in bringing their construction health and safety inventions to market.

2 Background

2.1 Innovation and Commercialization

Innovation can be defined as proposed by Garcia [6] "*Innovation is an iterative process initiated by the perception of a new market and/or new service opportunity for a technology based invention which leads to development, production, and marketing tasks striving for the commercial success of the invention*." The definition shows that innovation combines technical invention with market introduction and that the process is iterative, with subsequent innovation improving upon the prior, often as a result of market feedback. Technology commercialization overlaps with this definition as it is the process and a series of steps that move an invention from the early (idea) stages into a product or service. Similar definition is presented in CERF [7].

There are several models of technology commercialization: The Jolly Model with its sub-processes and bridging steps [8] the "Stage-Gate Process" [9] and other similar step-type processes used in technology management [10]. Overarching theme is that these models all begin with the basic scientific theory or newly discovered concept, continue through prototype and further development all the way to market introduction (and beyond). These general technology commercialization models also recognize several distinct phases in the process. Each approach may be more applicable to a different level of invention, technology area, or a technology development status.

"Successful" product in the marketplace should be self-sustaining (i.e. profitable enough to cover related manufacturing, distribution, and overhead) and also able to recover its commercial development costs.

The Jolly model [10] recognizes 5 distinct phases in this value development process:

1. **Imagine**, where an opportunity or a technology-market "match" is created and an idea is selected.
2. **Incubate**, that defines commercializability and that encompasses concept development.
3. **Demonstrate** which focuses on actual product development.
4. **Promote** includes introduction of the product into the marketplace.
5. **Sustain**, which is key to realizing value from the innovation.

The Jolly model also emphasizes four bridging steps between these phases that complete the process. Bridging steps have two conditions to allow the commercialization process to advance to the next phase: 1) demonstrating enough potential in the previous stage and 2) mobilizing sufficient (higher and higher) resources to proceed to the next stage, as the development costs increases significantly with each subsequent phase from Image to Sustain.

Literature recognizes two approaches to technology commercialization – Market Pull and Technology Push [10]. In Market Pull, a market problem/need exists and usually several competitors are trying to solve the problem to satisfy this need. Contrasting is Technology Push, where a capability given by a technology exists, but a solution, or a problem this capability can solve in the marketplace is yet unknown. A typical market pull can be often addressed by incremental (also continuous or sustaining) innovation, whereas a radical (discontinuous and disruptive) innovation will tend to be in the Technology Push framework. Despite this distinction, ultimately a successful commercialization will result in a market pull. As the authors argue further in this work, for sole university research, the early pull or existence of some customer needs is often first understood or discovered by the researchers in that area. Thus researchers in particular may be aware of opportunities on one hand, but also "blinded" by one area while dismissing other potentially more suited application area(s) for their technology.

Interesting for the case of health and safety in construction is the scarcely discussed type of "Regulatory Push" commercialization [10] common in some eco-innovations. In Regulatory Push, policymaker (or some governing body) decisions help effectively "push" certain technologies, standards, and solutions onto the market, often via subsidies or required/mandated standards.

2.2 The "Lean Startup"

There has been a new paradigm shift of how to create successful startup companies and launch new products to the market. Known as the "Lean Startup", the process focuses on searching for a business model (and sometimes new customers or channels) by creating, testing, and revising hypotheses made about the products and customer problems [11]. Contrary to the traditional practice of writing a business plan, creating market forecasts, and assuming customer needs before launching the product, the lean startup focuses on discovering the customers' problems right from the beginning, using feedback from potential users, purchasers, and partners to drive the path of the startup and product engineering. The purpose is to discover the minimum viable product (MVP), which only has the minimum features that allow the product to be deployed to solve the problem. Blank and Dorf [12] explain how "customer discovery" is one of the most important aspects of the lean startup, which uses a "get out of the building" approach by physically going out to acquire feedback on all elements of the business model. "Lean Startup" acquiring empirical feedback from the marketplace has analogies in industry, where large firms have previously performed "Probe & Learn" or "Expeditionary Marketing" efforts [13]. For a startup, this "Probe & Learn" process means nimble budget and very strict time constraints, or eliminating waste as in "Lean Manufacturing".

An important lean startup aspect is that startups are expected fail, and that quick and inexpensive failure accompanied by learning and potential pivoting moment as a result is seen as a success. Startups do not know the future, and therefore need to hypothesize. Lean Startups move from failure to failure, all the while adapting, iterating on, and improving their hypotheses as they continually learn from the customers [11, 12, 14]. This strategy greatly reduces the chances that startups will spend a lot of time and money launching products that no one actually will pay for [14] – recall that every later stage of product development becomes more and more expensive. Because they can move faster than established companies, startups can manage uncertainty, certain problems and ambiguities in the new product development process more effectively.

2.3 Research Design and Scientific Method

University researchers "live and breathe" research design and the scientific method. Creswell [15] outlines the necessary tools for proper research design. For the majority of research projects, the first step is to discover a problem or a question within the respected fields. Next is to conduct an extensive literature review of the problem, including what has been done, what needs to be done, and what could be done to solve the problem. During this review, the researcher narrows the scope of the problem and envisions possible solution(s) that can be applied to fix, mitigate, or eliminate the problem in question. The researcher may develop a technology or a new concept, or utilize/modify existing technology(ies) to apply towards the solution of the problem. Next, the researchers develop hypotheses, create experiments to test the hypotheses, and analyse the experimental data to support or refute the hypotheses.

In summary, proper and successful research design first starts with finding a problem, and then invents a technology or concept to provide a solution for that problem. This is the contrary to the idea of "Technology Push" – the practice of inventing or starting with a technology first and then trying to find a market to apply it to, which can often be difficult. Nevertheless, given the initial research problem, one could argue that there is no pure "Technology push" since the researches, even before embarking on a research project, already have some questions and problems in mind they are trying to resolve. Importantly, this early problem definition based on research problems, informs future market search. Significantly, these characteristics give researchers a greater advantage to commercialization than simply choosing a technology from an available list and pursuing an unknown area.

2.4 University Commercialization Funding, Support, and Infrastructure

There are various governmental and private programs that aim to aid the commercialization process at different stages, from early development all the way through capital investment. These programs can be beneficial for the commercialization of university research. Researchers should be aware of the many entrepreneurship and commercialization programs, supports, services, and even (non-dilutive) grant funding available on their university campus. The quantity and scope of these programs have grown dramatically in recent years. The National Science Foundation (NSF) Innovation Corps (I-Corps) was established to advance and commercialize NSF funded research. Some research universities may have established incubators, such as the Georgia Institute of Technology's VentureLab and Advanced Technology Development Center (ATDC), which are programs that support the successful development of entrepreneurial companies through various resources and services. The Georgia Research Alliance (GRA) coordinates research efforts between Georgia's public and private sectors in order to expand research and commercialization capacity in Georgia's universities.

At The University of Texas at Austin (UT-A) several programs exist in the engineering and business schools: The Idea to Product Program (I2P®) [1], Texas Venture Labs, and Master of Science in Technology Commercialization (MSTC) Program. Additionally Austin Technology Incubator (ATI), affiliated with UT-Austin (but somewhat separate) has a broad outreach and influence onto campus and to early-stage, student or faculty-run startups. ATI provides mentoring and guidance as well as expertise and access to outside entrepreneurship community. Such assistance programs are extremely beneficial, especially for university researchers, since they provide (free or affordable) critical resources, such as funding network or strategic guidance, which may be difficult for researchers to obtain initially.

3 Purpose, Scope, and Objectives

The purpose of this paper is to develop a general roadmap with guidelines for the commercialization of construction safety technology research. For this paper, the term "technology research" is a catch all, which may include an idea/solution, metric/rule, methodology, software program, or a tangible device. Because not every technology is the same, each may require different care, strategies, and decision making. Although there is no "perfect recipe", this work highlights general stages and steps. The scope is aimed at construction safety technology research and will draw from case studies in this field. This paper is focusing on the incubation period of commercialization, from the start of an idea through taking it out of the university's door into industry. Outlining details about taking the startup through major expansion, execution of a business plan, and growing to a successful business will not be fully covered in this paper. Additionally, legal aspects such as intellectual property (IP) are covered elsewhere in more detail [16]. Patents do underline successful technology commercialization and help maintain competitive advantage.

Academics and researches may be uncomfortable interacting with people outside their fields. However, the real world and successful business requires frequent interaction, especially with potential partners, financiers, and - most importantly - customers. This research paper aims to encourage and show scientific researchers that it is possible to commercialize technology and to create startups even without an extensive business background on their part. This work presents the integration of research design into current business commercialization techniques, giving researchers a guide for the commercialization process. However, some basic knowledge of business and IP is recommended.

4 Methodology

The methodology of this research is to first conduct an extensive literature review of current and past practices of commercialization to review the similarities between the options and highlight the benefits. Since researches excel at the research design and scientific method, it will be advantage to incorporate and apply these skills to the commercialization process. Case studies within the field of construction safety and health will be investigated. Additionally, a six month case study of the process of creating a startup company will also be examined.

Commercialization covers a broad scope of activities with varying definitions. For this paper, we are defining commercialization as the passing of university research from academia into the industry/marketplace. Three pathways that are identified for commercialization or dissemination of research are:

1. Inventors and founders form a startup
2. Company/industry buys/leases the technology rights (exclusive or non-exclusive) or IP
3. Open source (free-sharing and disclosure).

The first channel is when a startup is formed within the university. There are university programs that may assist (i.e., NSF I-Corps) in the formation of a startup to get the technology into the industry. The university may retain ownership stake of the startup, give/sell the ownership of the startup or another company outside of the university, or may claim royalties based on product revenues. These arrangements are usually negotiated with the Technology Transfer Office separately for each deal. The second path is straight forward, in which a company may invest or purchase research from a university to obtain technology IP rights to continue use or further expand. The third channel, often a strategic choice, is to make the research invention open source, which allows universal access to the research, invention, or other IP. However, there are still ways to make a profitable business model on an open source invention.

5 Case Study and Preliminary Results

A research project at the Georgia Institute of Technology has been selected to determine the feasibility of it to be commercialized. The research topic involves the integration of Building Information Modelling (BIM) for construction safety [4]. The process of creating a startup will be documented and the lessons learned will be discussed. In November 2013, the project went through the Gauntlet at the Georgia Institute of Technology, which is a smaller version of the I-Corps. During an intensive four week period, the group had to 1) identify the core of the business model; 2) create hypotheses about market problems, 3) interact with potential consumers to discover the market, 4) analyse results and update the business model. The purpose of the Gauntlet was to determine whether or not there is a product-market (techno-market) fit.

The first step of the project was to determine the marketability of the BIM safety rule checker, by which the group went "out of the building" to interact with potential users and customers in the construction industry. The purpose was to discover current problems companies have with BIM and safety. A total of 35 interviews were conducted within a 4 week period. The interviews were meant to gain insight, and not necessarily to be scientifically sound. The research ultimately applies to construction workers, and thus they were interviewed first, followed by construction safety researchers (due to their knowledge of construction safety). Afterwards, subcontractors and general contractors were interviewed. As a side note, the amount of interviews may seem modest, but research in new product development showed that for a single-function product, nine 1-hour long customer interviews uncover about 90% of customer needs that result from 60 interviews [17].

The following are the hypotheses that were tested with the conclusions made based on this primary research.

Hypothesis #1: Workers adhere to safety rules and standards for their protection. Workers will not always follow safety rules if it impedes with the task. Some admitted to not know exactly what the safe procedures are for the task. Getting the work done is the worker's priority, and not necessarily safety (might be secondary). However, for larger companies, workers tend to look out for one another's safety. Safety is important, but sometimes the reward is smaller than the risk.

Hypothesis #2: Preventative safety guidelines and leading indicators will help increase worker safety awareness. Research has shown a decrease of reported incidents with the increase of safety programs. Larger companies incorporate mandatory safety training programs and have reported great success in the increase of worker safety awareness.

Hypothesis #3: Construction companies want to increase worker safety and safe practices. Worker safety is the number one goal for construction companies. They use any resource available to them to improve safety standards.

Hypothesis #4: Construction companies have knowledge about BIM and are (or plan) using it. Most companies have knowledge of and use BIM. However, in many cases the companies neither use its full potential nor use it for the entire project duration. They are mostly using it for clash detections and inspections of installation. There is no record of using BIM for automatic safety code compliance.

Hypothesis #5: Companies will automate safety inspection. As safety is the main priority for companies, keeping workers safe while reducing cost is even better. Manual inspection takes much time, and thus companies are willing to invest in new technology to help automate it. Currently, some companies use software programs that let them leave inspection notes right into the BIM model, notifying personnel to fix the unsafe situation.

Hypothesis #6: Companies will invest in safety technology. As companies want to maximize safety, they also want to minimize cost. Companies are willing to invest in new technology that will increase technology and decrease costs. Safety technology has been proven to be successful in the construction industry. However, only larger companies are considerably willing to invest in new safety technology since they have more capital and can afford to recuperate losses. More companies are willing to invest if the cost of the technology is low and will reduce costs.

Additional lessons learned include:

- Large companies would rather pay a third party for a technology and invest in a proven technology (or assist university research) than developing it in-house.
- Companies would pay for a technology based on the project rather than license or purchase. The price of the technology for a project would be included in that project's budget.
- There are many unsolved problems with BIM that companies come across. Some are in early development with BIM and some relate to all aspects of the project (incl. logistics, laydown yards, storage, cranes, safety).
- The size of the project affects the safety procedures. Companies typically have a single safety inspector that inspects multiple sites. However, one company stated that large projects over $25 million would have a full time safety inspector. This fact inquires for additional research to investigate the differences between safety and incident rates on projects having a full time safety inspector versus a part time safety inspector.

Note that the interview population was not large enough for a full scientific validation or extrapolation for the entire industry. However, the results shed great light and provide direction for the startup. Again, the purpose of the Gauntlet was not to validate the research, but to give a binary "go/no go" status for the startup. In conclusion, it was determined that the research does have a product-market fit, and will pursue the next stages of the startup process.

6 Proposed Roadmap

The following is a proposed roadmap, which is a set of guidelines based on literature, empirical data, experience, and case studies. These guidelines are intended for university researches with a background in proper research design. Technology commercialization and reviewing an early-stage technology does not always result in a binary "yes/no" decision. Often, the recommendation based on market feedback may be that of "not right now", "not here", or "not at this price". Moving to the next phase will be also nuanced (i.e., yes if XYZ, no if ABC, yes in X months, no if this experiment fails). These steps are intended to be iterative, and thus they will be routinely repeated, each time resulting in refined business model to discover the features of minimal viable product (MVP).

6.1 Step I: Identifying the Problem

6.1.1 Utilize Research Design and Background

It is important to have a working knowledge of proper research design. The first step is to have a basic understanding of the problem being researched in the current field. The further along the research is to solving the problem with the technology the better. Here, the key is to not only understand how technology performs the function, but be able to describe what the technology does and the benefits it provides (often those benefits may be outside of first envisioned area). Similarly, it is important to know the problem that exists in the industry that a technology can (at least potentially) solve. When performing background research, one should also consider searching patent databases. Create testable hypotheses about the problems, including the root causes and possible solutions.

6.1.2 Learn How the World Works

Test your hypotheses. Testing the research hypotheses allows researcher to learn how the world works. Experiments, case studies, and analysis do validate research hypotheses, but learning how the world around the technology works determines a greater need for the technology. If the technology is proven to work, there is still a need to determine whether it is commercializable, and which features of the technology (MVP) are important to customers (the MVP) as benefits: e.g. the customer for a car may really be interested in moving herself from A to B (need) rather than possessing a metal box on wheels (one of many ways to satisfy the need). When a benefit is generalized along these lines, it becomes easier to address (in this case a train, airplane, bicycle, or feet can satisfy this customer need). The major influence of whether or not a technology is commercializable is whether there is a market for it. In order for a market to exist, the technology needs to solve an important enough problem (even a latent need, as is often the case in Technology push).

6.1.3 Interview Potential Customers/Stakeholders

Potential customer feedback and primary research is critical. There are numerous ways to talk to customers to gain valuable feedback. One must also gain an understanding of the buying process – who makes the purchase decision, who is the user, and who has the money and "writes the check" often these are, all different. The "end user" of the technology, which is the one who will either use the technology or benefit the greatest from the technology, should already be generally determined based on prior research. In terms of safety research, one can go to a location where the users would be, such as jobsites, factories, or offices, in order to talk to workers, project managers, etc. Use any resource available to contact customers, including current contacts, social media and blogs, and the phone book. Phone interviews and be a valuable and efficient resource. Trade associations could be an excellent information source for industry contacts or experts

6.1.4 Ask Questions

Proper discovery of how the world works starts with asking (open-ended) questions. Communicate effectively by taking interests in what problems the customers have to offer. It is important that these meetings are for "discovery" and not "selling" a product.

6.1.5 Evaluate Scientific and Research Hypotheses About the Technology Solution

In many ways, refuting a hypothesis and deciding not to proceed at a step can be very valuable not only to preserve vital resources, but also to inform the market and startup. After gaining feedback, re-evaluate the hypotheses about the problems, customers, markets and any unexpected discoveries. Make shifts in hypothesis to uncover the greater problems. Iterate until the MVP is discovered.

6.2 Step II: Determine the Target Market

Once the MVP is discovered, the next step is to investigate the overall market. It may be better to start small and then expand. To conduct the secondary and primary market research, utilize the same steps and techniques in Step 1, but this time focusing on the market information.

6.2.1 Secondary Market Research

Performing secondary market research will review reports, industry and market analysis/statistics, trade journals, and information available through business databases, including public companies filings or news releases to gather relevant information. Secondary research can help identify major players in industry, industry trends, as well as help estimate the possible market size for proposed product or service. In particular, initiating coverage reports, or S-1 filings of companies required by SEC before IPO include valuable market information in the intended space (the difficult part is finding a good, recently IPO-ed proxy-company).

6.2.2 Primary Market Research

This includes talking to potential customers, experts in the field, competitors, potential partners, other researchers, and overall gathers "primary" source information. This step overlaps with customer interviews, but here the focus is on understanding the market and space better at a higher level. Although this information is very valuable, it is good to cross-check previous data with interviewees, and make sure they converge or agree. Approximately 8-10 generally converging interviews will provide a good initial assessment. Again, excellent resources for market information are trade associations, as part of their mission is to aggregate and disseminate information about a very specific area.

6.3 Step III: Determine the Channel to Commercialize

It is important to determine what path to use to move the research outside of a university. The channel depends on the type of research, and each has benefits and drawbacks. Unless technology is straightforward fit, large companies purchase more developed third party tech (or smaller companies) that are already de-risked, even though it demands paying a premium – for a defined market, customer need, and a working solutions (and sometimes people talent).

6.3.1 Create Startup

Creating a startup is beneficial since the researches have been the motivation to the commercialization. Researchers take their vision and form a company to solve the problem. This is mostly suited for a tangible technology or invention (such as new safety equipment) but also for early stage inventions that have a limited chance of leaving the university and for success otherwise (not easy to license by a large company at this point, nor amenable to becoming public domain).

6.3.2 License

Licensing research (granting permission at a fee) may be suitable for certain types of research, such as in the field of chemistry (chemical patents) or computer science (software code or programs), where the technology may not be as complex as to require the inventor expertise on the team using it. It will also have to face only minimal implementation challenges into existing processes. An example in construction safety may include a plug-in software program that detects or analyses for safety issues.

6.3.3 Create Open Source (free-share)

Open source is the publishing of the research to grant free access. When there is a limited market to make profit (or there is not much need), or inventors intend to share their invention for public good, or invention can become a de-facto standard, this may be a preferred path. Data, source code, algorithms are popular candidates for open source. This can be a strategic choice when inventors chose not to pursue a technology, yet do not wish anyone else to have an exclusivity on it. Examples include algorithms, data, or source code.

6.4 Step IV: Determine a Business and Revenue Model

This step mostly applies to startups. The key to every successful business is revenue (and therefore profits). There are many potential business models based on any given technology. A startup will need to carefully consider its options and focus on the key expertise areas (or the most-value-added, profitable) functions in the entire product cycle and ecosystem. Other parts of the business (e.g., assembly and manufacturing, packaging, distribution) may best be outsourced. Here, strategic partnerships may play an important role not only in developing the technology but also in terms of channel-expertise. While commercializing a technology, this needs to be taken into account. Of course, all the while startup develops additional prototypes, focuses on benefits and tests or releases a minimally viable product (MVP).

6.5 Step V: Explore Channels to Receive Funding or Support

There are various governmental and private programs that help aid researchers in the commercialization process to bridge the early funding gap between research funding and a saleable product (customer or investor funding). Many universities now have programs for early stage development. Further grants may include various US Departments' Small Business Innovation Research (SBIR), emerging technology funds (ETFs), and other state, government, and industry consortia incentives.

Consider Strategic partnerships to help in development activities, especially between R&D and market, as well as customer channels where funding sources may be limited.

6.6 Step VI: Strategic Choices/Due Diligence with Legal and Financial Aspects

Each type of research, technology, market or customer, will vary. There is no a one approach-fits-all. The following list is outside of the work scope of this paper, but is important to keep in mind when conducting due diligence with legal and financial aspects:

- Intellectual search
- Projected expenses and financials
- Determine scope of IP and IP strategy overall

- Determine IP strategy best IP protection
- Determine the best capital investment funding opportunities
- Product development

7 Conclusion

The proposed roadmap was based on an extensive literature review, empirical data, experience, and case studies. The guidelines need to be tested and validated with future case studies. The BIM and safety startup will continue to be examined as it makes progress towards commercialization. The failures will be recorded and changes will be made accordingly as it continues through the commercialization process.

Important research questions to explore throughout this research and address include when one should step to the next stage, when to iterate, and when to abandon a technology for a given market or application. Additional research questions discovered are:

1. What metrics should be defined to determine when to go on to the next step?
2. Is market size/growth sufficient?
3. Is there sufficient market interest from potential customers and at what levels? (I.e. can it be filled with the technology product/service?)
4. How will the product transition from early users (evangelists/lead users) to the early majority?

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