



**DETERMINING THE DEGREE OF THE ROUTINIZATION OF ADDITIVE  
MANUFACTURING IN THE AIR LOGISTICS COMPLEXES**

THESIS

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AFIT-ENS-MS-16-M-098

**DEPARTMENT OF THE AIR FORCE  
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Candis A. Woods, BS

Captain, USAF

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## **Abstract**

Fiscal constraints have affected the United States Air Force's (USAF's) spending and sustainment of weapons systems that are being utilized beyond their programmed life cycle; therefore, it is imperative that processes be thoroughly evaluated for improvement, innovative approaches, and/or best practice implementation. The Air Force Sustainment Center (AFSC), part of the Air Force Materiel Command (AFMC), has embarked on a groundbreaking effort to transform operations and leverage industry best practices, while maintaining focus on warfighter support to create "The AFSC Way." The AFSC Way is based on a shared leadership model that emphasizes speed, safety, and quality, which gives way to innovative ideas and new technologies in order to achieve "Art of the Possible" results, despite fiscal uncertainty.

The quest for continued sustainment has led to the recognition of innovation as a vital ingredient to an organization's survival and profitability in this fiscally constrained environment. Additive manufacturing is one such innovation that the AFSC has adopted and implemented in an effort to maintain or enhance current weapons system sustainment practices. If the AFSC is to realize the potential benefits of additive manufacturing, it must be routinized to some degree into the organization's governance systems. This research concluded that additive manufacturing was moderately routinized in each ALC.

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Candis A. Woods

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# DETERMINING THE DEGREE OF THE ROUTINIZATION OF ADDITIVE MANUFACTURING IN THE AIR LOGISTICS COMPLEXES

## I. Introduction

### Overview

Fiscal constraints have affected the United States Air Force's (USAF's) spending and sustainment of weapons systems that are being utilized beyond their programmed life cycle; therefore, it is imperative that processes be thoroughly evaluated for improvement, innovative approaches, and/or best practice implementation. Military leaders, speaking about managing aircraft sustainment in the future, have bluntly stated, "We have two choices: accept the costs and reduce capability or change the way we do business" (AFSC, 2014). Electing to do the latter, USAF leadership instituted a large-scale supply chain management innovation designed to improve the \$16B per year maintenance, repair, and overhaul (MRO) enterprise in the Air Logistics Complexes (ALCs) responsible for sustaining its weapons systems (Douglas *et al.*, 2015).

The quest for continued sustainment has led to the recognition of innovation as a vital ingredient to an organization's survival and profitability in this fiscally constrained environment. Additive manufacturing is one such technological innovation that the Air Force Sustainment Center (AFSC) is pursuing to maintain or enhance current weapons system sustainment practices by researching and developing its short and long term applications.

The literature has revealed many research efforts dealing with organizational innovation adoption (Damanpour, 1991; Kimberly and Evanisko, 1981), but since Yin (1981), little

research has been conducted on how innovations become routinized into an organization (Yin, 1978; Zmud and Apple, 1992; Hazen *et al.*, 2012).

The focus of this research is to identify the degree of routinization of additive manufacturing in each of the three Air Logistics Complexes (ALCs). This study will be accomplished within the framework of Yin's passages and cycles of routinization to determine how their accomplishment affects an innovation's degree of routinization. The context of this investigation will be in relation to individual perceptions of the passages and cycles with respect to their respective ALC and how the evidence of specific passages and cycles affects the degree of the routinization of additive manufacturing.

## **Background**

The AFSC is on one six centers assigned to the Air Force Materiel Command (AFMC). Its mission and overarching focus is to provide sustainment and logistics readiness to deliver combat air power for America. The AFSC achieves this mission primarily through the three air logistics complexes (ALCs): Ogden ALC (OO-ALC), UT; Oklahoma City ALC (OK-ALC), OK; and Warner Robins ALC (WR-ALC), GA. The three ALCs are comprised of approximately 25,000 military, civilian, and contractor personnel who are responsible for providing depot-level MRO support to the USAF's extensive and aging weapons system inventory primarily through traditional maintenance and manufacturing practices.

In an environment where organizational resources are at an all-time low, the AFSC must provide the same or greater military capability and readiness to the USAF and DoD at less cost than before. To address this concern, the AFSC has embarked on a

groundbreaking effort to transform operations and leverage industry best practices, while maintaining focus on warfighter support to create “The AFSC Way.” The AFSC Way is based on a shared leadership model that emphasizes speed, safety, and quality, which gives way to innovative ideas and new technologies in order to achieve “Art of the Possible” results, despite fiscal uncertainty (AFSC, 2014). Achieving the goal of mastering the “Art of the Possible”, means fostering a culture in the ALCs focused on optimizing available resources and process improvement to achieve cost-effective readiness. The Air Force Chief of Staff recognized this fact when he stated, in his Air Force Vision Statement, “Faced with fiscal challenges, we must make prudent choices to ensure that the Air Force is able to release the full potential of airpower” (Welsh, 2013).

The AFSC Way is not about working harder, cutting corners, or jeopardizing workplace safety; it is about improving processes, maximizing available resources, and recognizing opportunities to use new technological innovations, such as additive manufacturing, to sustain weapons systems and provide continued support to the warfighter. Currently, the ALCs are using additive manufacturing technology in support of reverse engineering, rapid prototyping, and as a learning tool. There are a myriad of potential applications for additive manufacturing and an equal amount of methods to be used to construct three-dimensional (3-D) objects. If the ALCs are to eventually reap the full benefits of this technological innovation, it must first be routinized to the highest degree.

## **Problem and Purpose Statement**

The need for enhanced weapons system sustainment calls for a critical look at the passages and cycles of innovation routinization. Yin *et al.* (1978) identified nine passages and cycles that will be studied to determine their effect on an organization's degree of routinization of a specific innovation. The purpose of this research is to determine the degree of routinization of additive manufacturing by exploring personnel perceptions of the nine routinization passages and cycles to determine how their [routinization passages and cycles] accomplishment relates to an ALC's degree of routinization. Understanding an innovation's degree of routinization and what events affect that degree will allow an organization to direct their efforts on the accomplishment of certain passages and cycles to achieve a higher degree of routinization. This study will also address the disparities in the degree of routinization between the ALCs and make recommendations on how to achieve the highest degree of innovation routinization.

## **Research Question**

Given this problem, the research must be narrowed to a specific question. The focus of this research is to answer the following question: "How do the ALCs determine their degree of the routinization of additive manufacturing?"

## **Investigative Questions**

1. What passages and cycles contribute to determining an ALC's degree of the routinization of additive manufacturing?
2. What issues prohibit the ALCs from achieving the highest degree of the routinization of additive manufacturing?

3. What additional factors were found to affect the ALC's degree of the routinization of additive manufacturing?

### **Methodology**

A case study approach will be taken to determine an ALC's degree of routinization of additive manufacturing. Data will be triangulated and patterned matched to a theoretical proposition by examining the personnel perceptions of the accomplishment of specific routinization passages and cycles in the three ALCs. The rationale for selecting the qualitative research method employed in this research and the elements that lend this study to case study design as well as the data collection and analysis procedures will be detailed in Chapter III.

### **Assumptions/Limitations**

The exploratory nature of this study lends itself to one underlying assumption. With the focus of this study being on a specific post-adoption stage, it is assumed that the three ALCs have already adopted and implemented additive manufacturing. This study also has two fundamental limitations. First, literature on innovation routinization is limited. Secondly, additive manufacturing use in the ALCs is in its infancy; therefore, subject-matter-expert (SME) experience and practical application are limited.

### **Implications**

This study will be relevant to AFMC and AFSC leadership in that the results will provide a current assessment of the degree of the routinization of additive manufacturing in each ALC. It will also address the disparities in the degree of routinization between the ALCs and make recommendations on how to achieve the highest degree of

routinization. Achieving the highest degree of the routinization of additive manufacturing in the ALCs will place the AFSC one step closer to the incorporation of a vital capability that has the potential to reduce costs, waste, and wait times associated with traditional manufacturing.

## **Summary**

This chapter introduced the current problem, research question, investigative questions, and provided a summary of the methodology used in this study. Chapter II presents an in-depth review of the existing literature on additive manufacturing and innovation routinization. Chapter III further describes the research and data collection methodology used to accomplish the objectives of this study. Chapter IV presents the analysis, while Chapter V provides conclusions, recommendations, and offers areas for further research.

## **II. Literature Review**

### **Overview**

This chapter provides a review of the literature relevant to both additive manufacturing and organizational innovation routinization. This review will first give a general overview of additive manufacturing. Next, innovation will be discussed by exploring the following areas: innovation, innovation type, and Innovation Diffusion Theory. Finally, the review will discuss post-adoption innovation diffusion, routinization, and the nine passages and cycles of routinization and their subsequent relationship on an organization's degree of routinization.

### **Additive Manufacturing**

Additive manufacturing is addressed as a technological innovation in a variety of past supply chain management (SCM) studies (Walter *et al.*, 2004; Campbell *et al.*, 2012)--dating back almost 40 years and is poised to transform the industrial economy (Hauge, 2004). Although additive manufacturing has been around in the private sector for decades, it has recently caught the attention of AFMC to research practical applications that have the potential to enhance current and future weapons system sustainment processes. Additive manufacturing is a technique that combines planar layers of material, similar to that of ink-jet printers, sequentially to form three-dimensional (3-D) objects. The literature reveals additive manufacturing is synonymous with 3-D printing, additive processes, layered manufacturing, free-form manufacturing, and rapid manufacturing (Raja *et al.*, 2006; Petrovic *et al.*, 2011). Additive manufacturing is ideal for customized parts with short fabrication series--its extreme

flexibility not only allows for easy customization of goods; but also eliminates assembly and enables products to be designed or redesigned for higher performance (D'Aveni, 2015).

Currently, the most lucrative field of application for additive manufacturing is found in the biomedical industry for the production of customized hearing aids and surgical implants (Petrovic *et al.*, 2011). The aerospace industry has found that this technology has benefits for the rapid manufacturing of aircraft tooling, tools, and ultimately end-use parts (Walter *et al.*, 2004). Tooling is “the cutting or shaping part in a machine or machine tool”, whereas a tool is “a handheld device that aids in accomplishing a task” (Tooling, 2015; Tool, 2015). “End-use parts” are flight certified flight or non-flight critical components installed on a weapons system to provide a specified level of functionality. Depending on the complexity and technique used, additive manufacturing has the ability to eliminate many traditional manufacturing constraints to make way for customized mission support. The literature identifies four additive manufacturing techniques currently used in industry. Those applications are found below.

### ***Rapid Prototyping.***

Rapid prototyping allows for the quick production of physical prototypes with the benefit of reducing the time to market (Raja *et al.*, 2006). In the past fourteen years, a number of new rapid manufacturing systems have been developed. This development permits the concept conversion of a complex component into a solid replica in a matter of days, whereas traditional prototyping systems would require an extended amount of time. All rapid prototyping techniques begin with a CAD model of the part to be made. The

computer then slices the part into thin layers and feed the information on the shape and dimensions of each layer to the manufacturing system. The systems differ in the way the component is built up layer by layer. Currently, the most frequently used methods are fused deposition modeling (FDM), binder-jetting, and direct metal laser sintering (DMLS).

### **Fused Deposition Modeling.**

The FDM method forms 3-D objects from computer generated solid or surface models. Models can also be derived from computer tomography scans, magnetic resonance imaging scans, or model data created from 3-D object digitizing systems (Zein *et al.*, 2002). FDM uses a small temperature controlled extruder to force out a thermoplastic filament material and deposit the semi-molten polymer onto a platform in a layer-by-layer process. The monofilament is moved by two rollers and acts as a piston to drive the semi-molten polymer. At the end of each finished layer, the base platform is lowered and the next layer is deposited. The designed object is fabricated as a 3-D part based solely on the precise deposition of thin layers of the polymer. The deposition path and parameters for every layer are designated depending on the material used, fabrication conditions, applications of the designed part, and the preferences of the designer (Zein *et al.*, 2002). The main advantages of the FDM method are the fabrication of low cost parts and the ability to coat the surface to improve its quality (Petrovic *et al.*, 2011). Conversely, the disadvantages are poor surface quality with grainy appearance and poor dimensional precision (Petrovic *et al.*, 2011).

### **Binder Jetting.**

The binder jetting process uses two materials; a powder based material and a binder. The liquid binder acts as an adhesive between powder layers. A print head moves horizontally along the x and y axes of the machine and deposits alternating layers of the build and binding material to produce a 3-D object. Due to the method of binding, the material characteristics are not always suitable for structural parts, and despite the relative speed of printing, additional post-processing (cure) can add significant time to the overall process (Harris, 2015).

### **Direct Metal Laser Sintering.**

DMLS fabricates metal prototypes and tools directly from CAD data. This process is popular in rapid tooling, since suitable metal powders can be used to produce metal parts and tools (Simichi *et al.*, 2003). Although this is a popular method, the properties of the parts depend on its composition and solidification conditions. Accuracy, wear-resistance, and mechanical properties are critical in choosing the correct rapid tooling part as the production-grade part (Khaing *et al.*, 2001).

### ***Rapid Tooling.***

Rapid tooling is the result of combining rapid prototyping techniques with conventional tooling practices to manufacture moulds and dies from CAD data with a shorter lead time and at a lower cost relative to traditional manufacturing methods. This technology is currently best justified for small-batch manufacturing of prototypes used for functional testing or production process design and evaluation purposes (Raja *et al.*, 2006).

### ***Reverse Engineering.***

Reverse engineering is a method for constructing CAD models of physical parts by digitizing an existing part. A typical system consists of two parts: a measuring machine to digitize the physical model surface in the form of a point cloud, and software to create the surface and solid models from the point cloud. This method is oftentimes the only method available when the specification diagrams for physical objects are no longer available. The main benefit of reverse engineering is that it is a powerful tool in inspecting physical models, especially with complex spatial positions and orientation geometrical features (Raja *et al.*, 2006).

### ***Rapid Manufacturing.***

Hauge *et al.* (2004:4693) defines rapid manufacturing as the, “production of end-use parts through additive manufacturing systems.” There are few large-scale applications of rapid manufacturing, many of which are found in the biomedical field. Although the capability exists to manufacture end-use parts, special attention needs to be paid to the manufacturing process, materials, design of the part, and overall management of the process (Mellor *et al.*, 2014).

### **Innovation**

Research suggests that the need for organizational innovation is typically stimulated by a “performance gap” between actual and desired results (Rogers, 2003). A performance gap may be discovered within units under the same parent organization, in comparison to other DoD agencies, or missed opportunities to capitalize on industry best practices. By innovating, an organization is engaged in a learning process by which it

discovers new ideas by re-combing existing ideas in new ways with the intent of increasing organizational performance (Damanpour, 1991; Tavassoli and Karlsson, 2015).

Rogers defines innovation as, “an idea, practice, or object that is perceived as new by an individual or other unit of adoption”, whereas a technology is, “a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcome” (Rogers, 2003:12-13). As such, nearly any contemporary idea, practice, or product that an organization wishes to adopt and employ for the purpose of obtaining gains in performance can be thought of as a technological innovation (Hazen *et al.*, 2012:120). Yeo *et al.* (2015:153) further elaborates stating, “Technological innovations are the successful adoption of technology-based inventions for products and processes.”

In studies of innovation, there is a need to differentiate between various categories of innovations so that consistency in the comparison of findings can be maintained (Damanpour, 1989). Additionally, different types of innovations go through different types of adoption processes and have different determinants (Damanpour, 1991). Innovation cannot be understood without careful attention to the personal, organizational, technological, and environmental context for which it takes place (Wolfe, 1994).

### **Types of Innovation**

Due to the complex, context-sensitive, nature of innovations, they are frequently classified into typologies as a means of identifying their innovative characteristics or degree of innovativeness (Wolfe, 1994; Garcia and Calantone, 2002). There are three

distinct pairs of innovation types: administrative and technical, product and process, and radical and incremental.

***Administrative/Technical.***

Administrative innovations involve organizational structure and administrative processes. They constitute the introduction of a new management system, administrative process, or staff development programs (Damanpour, 1991). An administrative innovation does not provide a new product or a new service, but indirectly influences the introduction of those products or services or the process of producing them (Kimberly and Evanisko, 1981). Technical innovations pertain to new products, services, and production process technology. Unlike administrative innovations, technical innovations are directly related to the basic work activities of the product or process (Damanpour, 1991).

***Product/Process.***

Product innovations are new products, equipment, or services introduced to meet an external user or market need (Damanpour, 1991). Process innovations improve organizational processes by introducing new elements into organizational operations to support the production of a product or service (Damanpour, 1991). Product innovations have a market focus and are primarily customer driven, while process innovations have an internal focus and are primarily efficiency driven.

***Radical/Incremental.***

Radical or transformational innovations are those that seek to initiate fundamental departures from current projects, products, or procedures of organizations. Additionally, radical innovations often do not address a recognized demand, but instead create a

demand previously unrecognized by the consumer. This new demand cultivates new industries with new competitors, firms, distribution channels, and new marketing activities (Garcia and Calantone, 2002). Incremental innovations are those that seek smaller scale departures from existing organization practices through minor improvements or adjustments in current technology or task systems (Damanpour, 1991). Technological innovations are typically categorized into these two categories.

### **Diffusion of Innovation Theory**

For decades, researchers belonging to various disciplines, such as psychology, sociology, economics, anthropology, and organization theory have studied organizational innovation at great lengths (Rogers, 2003). The focus of early research was on theory development without regard for the type of innovation, while more recent research has broadened innovation theory. The diffusion of innovation theory is considered the first theory of innovation acceptance, and has its early roots in rural sociology where it was developed to explain and predict how agricultural innovations were diffused (Rogers, 2003).

Diffusion as defined by Rogers is, “the process by which an innovation is communicated through certain channels over time among the members of a social system” (Rogers, 2003:5). It has since been tested and refined in nearly 9,000 published studies of innovation adoption across a wide range of scholarly disciplines. Rogers proposed a five-stage innovation-decision process model that can lead an organization to adopt or reject an innovation. He defined the adoption process as “the process through which an adopter unit passes first knowledge of an innovation, to forming an attitude, to a

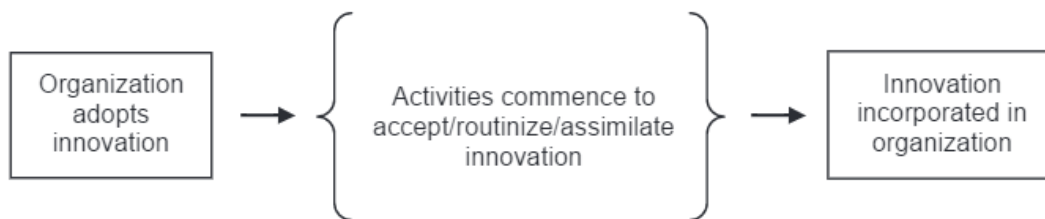
decision to adopt or reject, to implementation, and to confirmation of this decision” (Rogers, 2003:169). In particular, he argued that the decision to adopt and use an innovation unfolds in the following five stages.

1. *Knowledge*. In this stage, a member becomes aware of the existence and uses of an innovation (Rogers, 2003).
2. *Persuasion*. In this stage, a member forms a favorable or unfavorable attitude toward the innovation. It is the stage of being persuaded to adopt the innovation (Rogers, 2003).
3. *Decision*. In this stage, a member engages in activities that lead to making a choice of adopting or rejecting the innovation. (Rogers, 2003).
4. *Implementation*. In this stage, a member actually begins using the innovation (Rogers, 2003).
5. *Confirmation*. Finally, this stage determines whether the member accepts or rejects the innovation. It is the stage of evaluating the actual outcomes with expectations (Rogers, 2003).

The first two stages of the model (knowledge and persuasion) can be characterized as the initiation activity in the overall innovation process, whereas the last two stages (implementation and confirmation) represent the implementation activity. The decision to either adopt or reject the innovation in stage three links the two activities together. Hazen *et al.* (2012) argue that adoption is only one aspect of innovation diffusion. To achieve the ultimate goal of incorporating an innovation into an organization, special attention must be paid to the stages or events between adoption and incorporation if an organization is to reap the potential benefits of the innovation.

## Post-Adoption Innovation Diffusion Activities

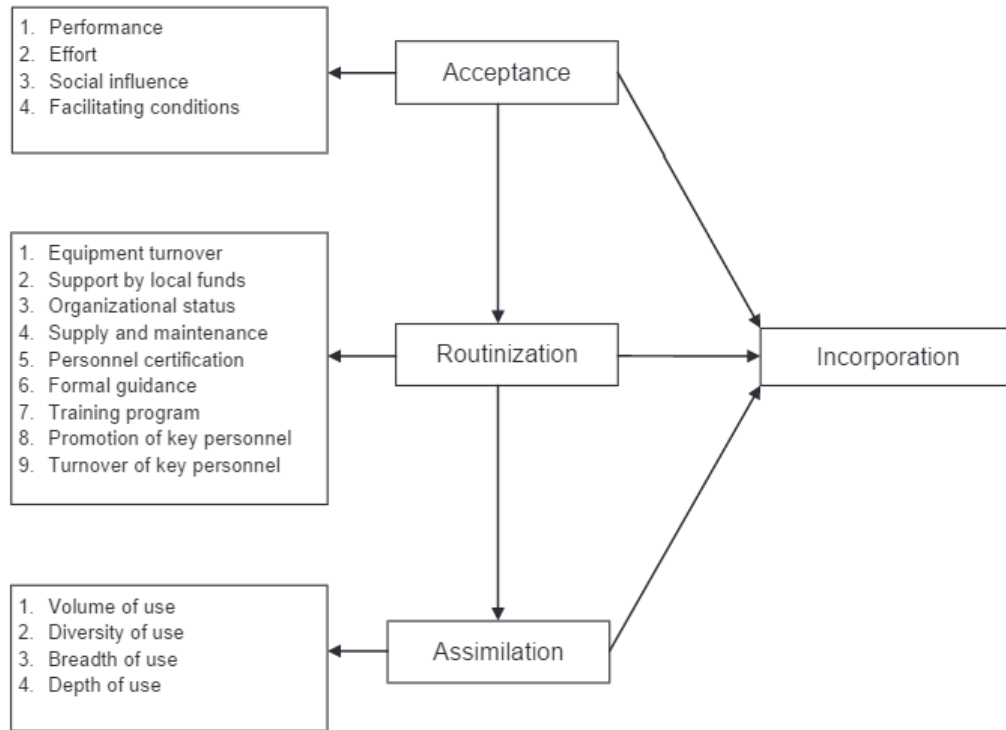
Regardless of an organization's motive for acquiring an innovation, the innovation must be incorporated into the organization--to some degree--if it is to fully reap the benefits of the innovation (Hazen *et al.*, 2012). Incorporation, as defined by Zmud and Apple (1992:148), is "the point when an adopted innovation is fully embedded within an organization." A variety of diffusion activities serve to facilitate the incorporation of an innovation. Hazen *et al.* (2012) categorized those activities into three stages: acceptance, routinization, and assimilation. Figure 1 depicts the post-adoption innovation diffusion process that begins when an organization adopts an innovation, and ends with incorporation.



**Figure 1: Post-adoption Innovation Diffusion (Hazen *et al.*, 2012:122)**

During the acceptance stage, an innovation is implemented steadily throughout the organization and its members gradually gain a clear understanding of the innovation and its implications (Hazen *et al.*, 2012:121). During the routinization stage, an organization's governance systems are adjusted to accommodate the innovation in order for the innovation to be seen as a standard practice. Assimilation is viewed as the extent to which the innovation has diffused across organizational processes (Hazen *et al.*, 2012:127). Innovation research drawn from various disciplines was used as a basis for identifying specific activities that were relevant to each stage. From these constructs,

Hazen *et al* (2012) developed a unified framework of how the three post-adoption stage activities occur—often times simultaneously—to achieve the ultimate end-state of incorporation, Figure 2.



**Figure 2: Unified Framework of Post-adoption Activities (Hazen *et al.*, 2012:128)**

Although this framework does not place emphasis on particular stage of the innovation diffusion process, it provides the field with a solid foundation of how to achieve innovation incorporation. For the purpose of this study, the researcher will focus on the routinization stage to gain an understanding how adjusting an organization’s governance systems for an innovation will aid in achieving incorporation.

## **Routinization**

Routinization is the point where an innovation is no longer regarded as an “innovation”, but as a standard practice of the organization (Yin *et al.*, 1978:v). Zmud and Apple (1992:149) add that it is, “the permanent adjustment of an organization’s governance system to account for the incorporation of a technology.” To gain a better understanding of innovation routinization, Yin *et al.* (1978) conducted a longitudinal study of several technological innovations in a variety of settings. Those six innovations were selected based upon the similarities they shared with respect to the: type of innovation, innovation characteristics, and location of the innovation. The life histories of those innovations were analyzed against passages and cycles developed from the five types of resources needed to sustain an innovation: budgetary resources, personnel resources, training programs, organizational governance, and supply and maintenance operations (Yin, 1978).

## **Passages and Cycles**

To gain support from these resources, an innovation must achieve a series of passages or cycles. A "passage" occurs when a formal transition from one organizational state to another has taken place (Yin *et al.*, 1978). For instance, new job skills often require the establishment of specific personnel classifications in the civil service system. The actual establishment of such classifications would constitute a passage. Similarly, the change from an external to internal source of funding would also serve as a passage. In this case, the term "passage" is used to define significant changes in organizational procedures or structure that reflect increased organizational support for an innovation

(Yin *et al.*, 1978). In contrast, a "cycle" is an organizational event that occurs repeatedly during the lifetime of an organization. Each time a cycle occurs; the use of an innovation may be questioned and threatened. The term "cycle" thus applies to repeated events that occur as part of an organization's operations and that may affect an innovation (Yin *et al.*, 1978). Although the routinization of an innovation can never fully be measured, its degree may be described in terms of its ability to negotiate several passages as well as its ability to survive a period of organizational cycles. To further elaborate this concept of routinization, the following paragraphs describe the nine organizational events Yin *et al.* (1978) conceptualized as passages and cycles that must be achieved if an organization is to achieve the highest degree of innovation routinization.

1. *Equipment Turnover (cycle)*. Degree to which procedures are established for acquiring new generations of equipment needed to update the innovation (Yin, 1981).
2. *Support by Local Funds (passage)*. Degree to which the innovation is supported by the normal or local budgeting process (Yin, 1981).
3. *Organizational Status (passage)*. Degree to which the innovation and associated practices are located in the appropriate organizational unit (Yin, 1981).
4. *Supply and Maintenance (passage)*. Degree to which supplies and repairs can be obtained according to normal organizational procedures (Yin, 1981).
5. *Personnel Certification (passage)*. Degree to which the organization is able to hire and sustain individuals qualified to work with the innovation (Yin, 1981).
6. *Formal Guidance (passage)*. Degree to which formal regulations and governing ordinances are established and updated to account for the innovation (Yin, 1981).

7. *Training Program (passage)*. Degree to which the organization offers opportunities for initial and/or recurring training regarding the innovation (Yin, 1981).
8. *Promotion of Key Personnel (cycle)*. Degree to which persons familiar with the innovation have been promoted into positions of greater authority such that they may support the innovation further (Yin, 1981).
9. *Turnover of Key Personnel (cycle)*. Degree to which the innovation serves a purpose in the organization after the original personnel involved in adoption and implementation have moved on (Yin, 1981).

Yin *et al.* (1978) concluded that the accomplishment of the above passages and cycles was directly related to an innovation's degree of routinization, and identified three degree classifications based on the number of passages and cycles accomplished. Those classifications were: poorly routinized = 1-3 passages and/or cycles accomplished, moderately routinized = 4-6 passages and/or cycles accomplished, and highly routinized = 7-9 passages and/or cycles accomplished. The above passages and cycles and degree classification will be analyzed in the following chapters.

## **Summary**

This chapter explored the literature related to additive manufacturing and innovation routinization. Sources that were related to innovation routinization were limited; therefore, emphasis was placed on few sources specific to this area. The following chapter provides the research design and methodology used in this study, as well as the steps necessary to answer the investigative questions presented in Chapter I.

### **III. Methodology**

#### **Overview**

This chapter provides the rationale for selecting the qualitative research method employed in this research, and the elements that lend the study to case study design. It introduces the case study subjects as well as explains the data collection and analysis procedures.

#### **Research Plan**

Traditionally, quantitative research involves measurable variables, while qualitative research is comprised of descriptive or verbal data and is typically used to answer questions about the nature of phenomena (Leedy and Ormrod, 2010). To that end, Yin (2014:9) suggests that “the first and most important condition for differentiating among the various research strategies is to identify the type of research question being asked.” Since this research will examine the degree of innovation routinization in the ALCS by asking “how” and “why” questions, a qualitative research design is appropriate for this study. Further, while there are many approaches to qualitative research. A case study strategy, explained below, will be used for this research.

According to Yin (2014), there are three conditions for determining the proper fit of a research strategy. These three conditions consist of: the type of research question posed, the extent of control an investigator has over actual behavior events, and the degree of focus on contemporary as opposed to historical events (Yin, 2014:9). Table 1 below offers a comparison of the five major research strategies that address these conditions.

**Table 1: Comparison of Research Strategies (Yin, 2014:9)**

<b>Strategy</b>	<b>Form of the research question</b>	<b>Control over behavioral events?</b>	<b>Focus on current events?</b>
Experiment	how, why	Yes	Yes
Survey	who, what, where, how many, how much	No	Yes
Archival Analysis	who, what, where, how many, how much	No	Yes/No
History	how, why	No	No
Case Study	how, why	No	Yes

The case study research method was preferred to other research methods such as experiment and survey, strictly due to the nature of the research question. Yin (2014) identified a case study as the preferred method when “how” or “why” questions are being asked about a contemporary set of events, over which the investigator has little or no control. While the case study method may be the preferred, there are limitations of using it as a research methodology. The biggest limitation is that the case study has the potential of being subjective (Leedy and Ormrod, 2010). Another limitation is that the quality of the data relies on the knowledge and skills of the investigator. If an

interviewer has poor interviewing skills, the collected data could contain poor information which could adversely affect the outcome of the study.

***Case Study Subjects.***

The additive manufacturing SMEs included in this study are assigned to the Commodities Maintenance Group (CMXG), Aircraft Maintenance Group (AMXG), and Maintenance Support Group (MXSG) in the three ALCs: Warner Robins Air Logistics Complex (WR-ALC), Warner Robins AFB, Georgia; Ogden Air Logistics Complex (OO-ALC), Hill AFB, Utah; and Oklahoma City Air Logistics Complex (OC-ALC), Tinker AFB, Oklahoma. The ALCs are comprised of a mix of USAF officers, enlisted personnel, and DoD civilians assigned to various aspects of weapons system sustainment for A-10, F-16, F-15, F-22, F-35, C-130, T-38, KC-135, B-1, B-52, E-3, C-17, C-5 aircraft.

The CMXG directs, manages, and operates organic depot level maintenance facilities in the restoration of USAF and United States Navy (USN) aircraft and engine parts to serviceable condition. The group is also the Air Force Technology Repair Center for air & fuel accessories, constant speed drives, and oxygen related components.

The AMXG directs, manages and accomplishes organic depot-level maintenance, repair, modification, overhaul, functional check flights and reclamation of various military aircraft. The group conducts depot support operations on a fleet of USAF, Air Force Reserve (AFR), Air National Guard (ANG), USN and Foreign Military Sales aircraft, as well as expeditionary combat-logistics depot maintenance and distribution support.

The MXSG manages industrial services, physical sciences laboratories, precision measurement equipment laboratories and tools. It provides engineering, installation, maintenance and management support for industrial plant equipment and facilities. In addition, the group provides environmental, occupational health, continuous process improvement and point of use technology for all complex organizations.

## **Design**

Yin (2014:29) suggests that there are five components of a research design: “a study’s questions, its propositions, if any, its unit(s) of analysis, the logic linking the data to the propositions, and the criteria for interpreting the findings.”

The *study questions* are the first component; they clarify the nature of the study and provide clues regarding the most relevant research method to be used. As previously noted, the nature of this study is “how” to determine an ALCs degree of innovation routinization.

Since the study questions do not sufficiently indicate exactly what the research should examine, the *propositions* direct the researcher’s attention to relevant evidence that should be examined within the scope of the study (Yin, 2014). This research utilized the passages and cycles identified in Chapter II as an innovation routinization framework to be applied to this study; therefore, the study proposition became “how does the accomplishment of certain passages and cycles relate to an innovation’s degree of routinization?”

The *units of analysis* define the “case” to be studied (Yin, 2014:31). For this research, the units of analysis are the three ALCs. A multiple case study design was

selected due to it being appropriate to make comparisons, build theory, or propose generalizations (Leedy and Ormrod, 2010). The passages and cycles of routinization presented in Chapter II will be used to determine the degree of the routinization of additive manufacturing in each of the ALCs.

*Linking data to propositions and criteria for interpreting the findings* are the last two components of research design. These two components will aid the researcher in determining which data analysis technique(s) to use and how to draw conclusions based on the collected data. For this study, the researcher developed key words for each proposition, then linked the data to each proposition through pattern matching to the established key words.

#### ***Quality of Design.***

Case study methodology is often criticized for a lack of rigor; therefore, Yin (2014) suggests a number of methods to judge the quality of the research design. Four tests have been commonly used to establish the quality of any social science research and are relevant to case study research as well (Yin, 2014). Table 2 below summarizes the four tests and the associated case study tactics, followed by a discussion of each test.

**Table 2: Case Study Tactics for Four Design Tests (Yin, 2014:9)**

Tests	Case Study Tactic	Applicable Phase of Research
Construct validity	- Use multiple sources of evidence	Data collection
	- Establish chain of evidence	Data collection
	- Have key informants review draft case study report	Composition
Internal validity	- Do pattern-matching	Data collection
	- Do explanation-building	Data collection
	- Address rival explanations	Data collection
	- Use logic models	Data collection
External validity	- Use theory in single-case studies	Research design
	- Use replication logic in multiple-case studies	Research design
Reliability	- Use case study protocol	Data collection
	- Develop case study database	Data collection

*Construct validity* is “the establishment of correct operational measures for the concepts being studied. The responsibility falls on the researcher to support the claim that the criteria used during data collection was more than a series of subjective judgements (Yin, 2014). In this research, construct validity was maintained by triangulating data from multiple sources.

*Internal validity* is important for explanatory or causal studies. It allows the researcher to draw conclusions about casual relationships and other relationships in the data (Yin, 2014:46). The literature provided a measurement for how to determine the degree of innovation routinization based on the accomplishment of the passages and/or cycles of routinization. Internal validity was further ensured by pattern matching

personnel perceptions to the theoretical proposition, “how does the accomplishment of certain passages and cycles relate to an innovation’s degree of routinization?”

*External validity* is the extent to which a study’s findings can be generalized (Yin, 2014:46). The literature review provided support that the passages and cycles of routinization used in this study had applicability to other innovations.

*Reliability* is demonstrating that the operations of a study can be repeated, with the same results (Yin, 2014:46). However, Yin cautions that in case study research “the emphasis is on doing the same case over again, not on ‘replicating’ the results of one case by doing another case study” (2014:49). He compares reliability to the question of generalizability, in that, “the uniqueness of a study within a specific context mitigates against replicating it exactly in another context” (Yin, 2014:159). Reliability was maintained by archiving the collected data in a case study database.

## **Prepare**

Once the case study method is selected and the research and investigative questions are identified, the next step is to prepare to conduct the case study (Yin, 2014). The data collection method of this case study includes interviews; therefore, specific ethical considerations regarding human subjects must be followed.

### ***Human subjects interview requirements.***

This case study includes interviews with various stakeholders in weapons system sustainment. The researcher conducted basic human subject research training designed by the Collaborative Institutional Training Initiative (CITI). The training topics included, but were not limited to: history and ethics of human subjects research, federal

regulations, informed consent, and basic institutional review board (IRB) regulations and review processes.

This research qualified for an exemption from human experimentation requirements because the researcher followed procedures to safeguard any personally identifiable information (PII) to avoid putting the subjects at risk of criminal or civil liability or the potential to damage the subjects' financial standing, employability, or reputation. The approved exemption memorandum is provided in Appendix A. The interview documents will be kept separate and accessible only to the researcher. Additionally, the interview subjects were required to sign a consent form detailing the interview procedures, risks, and additional consent for the interview to be recorded and transcribed. A sample consent form is provided in Appendix C.

***Interview methods.***

It is imperative that the data collection procedures be identified in the preparation stage. The study will use semi-structured interviews to collect perceptions of the specified subjects. The interview subjects were determined based on their role in the research and development of additive manufacturing in their respective ALC. Although the method of reaching the interview subjects was limited by time, ability to travel and funds, the researcher was able to travel to each ALC to conduct in-person interviews.

***Access to interview subjects.***

Potential interview subjects were first identified by AFIT faculty. Thereafter, subsequent interview subjects were suggested by name due to personal or professional relationships with the previous subject and their relationship with additive manufacturing in their respective organizations. Since additive manufacturing is regarded as a new

innovation in the ALCs, SME are limited to those that currently work with the innovation. The interview subjects were identified as SMEs in their organization; therefore, they were deemed qualified to participate in this study. The demographics of the interview subjects are shown in Table 3. Each interview subject was provided a consent form and research talking paper. Examples of these items are provided as Appendix C and Appendix B, respectively.

**Table 3: Interview Subjects Demographics**

<b>Respondent</b>	<b>Sex</b>	<b>Grade</b>	<b>ALC</b>	<b>Prior AM Experience</b>	<b>Time in Current Position</b>	<b>Engineering Background</b>
1	M	GS-14	A	Yes	2 years	Mechanical
2	M	GS-13	B	No	2 years	Mechanical
3	M	GS-11	B	No	2 years	Mechanical
4	M	GS-11	B	No	2 years	Mechanical
5	M	O-2	B	No	1 year	Materials
6	M	O-1	B	No	10 months	Mechanical
7	M	GS-11	C	No	1.5 years	Mechanical
8	M	GS-11	C	No	1.5 years	Mechanical
9	M	GS-11	C	No	1.5 years	Mechanical

### ***Interview questions.***

The next step in the preparation stage is to create a set of questions to guide the discussion during the interviews. These questions were used to start the discussions and appropriate follow on questions were asked based on the subjects' response. The questions varied slightly based on the subjects' level of expertise, but were similar for each of the interviews. Interview subjects were informed that the objectives of the interview were to understand the routinization process for additive manufacturing in their respective ALC. The questions were developed around the theoretical proposition, "how does the accomplishment of certain passages and cycles relate to an innovation's degree of routinization?" The researcher developed questions specific to each passage and cycle that would provide evidence towards its [passages and cycles] accomplishment.

Interview questions can be found in Appendix D.

### **Collect**

Multiple sources of evidence were used to collect data for the case study. The data was recorded in a case study database and multiple chains of evidence used to verify findings. The sources of evidence used included interviews and direct observations.

#### ***Interviews.***

Approximately nine semi-structured interviews were conducted at the three ALCs with the target population being the experts working with additive manufacturing in the CMXG, AMXG, and MXSG. Their involvement ranged from chief engineer to materials research and development. Interviews ranged from 20 minutes to 60 minutes, depending

on the level of involvement and the amount of information the subjects were willing to provide. Anonymity was provided for all respondents.

### ***Direct Observations.***

The researcher conducted an initial site visit to the AFSC in June 2015 to gain exposure to depot maintenance. During this visit, the researcher gathered information through informal discussions, conducted shop walk throughs, prepared for interviews, and conducted research on additive manufacturing and its practical applications. During the shop walk throughs, the researcher was able to see how an object is scanned into CAD or point cloud software and sent to an additive manufacturing machine to be manufactured into a 3-D object. The researcher also saw first-hand 3-D objects that had been printed to gain familiarity with the technology. These objects can be seen in Appendix E.

### **Analysis**

A detailed analysis of the collected data will be provided in Chapter IV. This analysis will rely on pattern matching guided by the theoretical propositions (passages and cycles of routinization) identified in the literature review.

### **Share**

Once this case study is completed, the information will be presented to the AFIT community in a thesis report and thesis defense briefing. The information found in this case study may be of assistance to personnel seeking to routinize innovations in their organization.

## IV. Analysis and Results

### Overview

This chapter presents the analysis of the responses gathered from personal interviews conducted from 4 January 2016 – 8 January 2016. First, an example of the pattern matching matrix will be provided. Next, the matrix will show how specific quotations from respondents were matched to specific passages and cycles. Lastly, an analysis of each passage and cycle will be presented based on the perceptions of the interview subjects, followed by a brief conclusion to explain the overall result.

### Analysis

The researcher developed key words to match interview data with specific passages and cycles. The key words were not all inclusive, and the researcher relied on her engineering and maintenance background to match data to passages and cycles when appropriate. Table 4 identifies the key words used to categorize the data by passages and cycles.

**Table 4: Key Word Matrix**

<b>Passage or Cycle</b>	<b>Key Words</b>
Equipment Turnover	Machine type, maintenance, projects, uses
Support by Local Funds	Established budget, budget, funds request process
Supply and Maintenance	In-house, out-house, materials, warranty
Personnel Certification	Prior experience, length of time with AM, special certification
Formal Guidance	AFIs, official memorandums, verbal guidance
Training Program	Trainers, training report, proficiency
Promotion of Key Personnel	Promotions, new hires,
Turnover of Key Personnel	New hires, gaps in personnel, manning

Next, using the key words associated with the passages and cycles, the researcher analyzed the interview responses and determined which passage and/or cycle the information fit. A sample analysis can be seen in Table 5.

**Table 5: Respondent Responses**

Passage or Cycle	Key Words	ALC A: Respondent 1
Equipment Turnover	Machine type, maintenance, projects, uses	"I will be submitting a request for a DSLM in the next fiscal year", "Equipment is the easy part, we just really have no justification for it right now"
Support by Local Funds	Established budget, budget, funds request process	"Funding is also an easy part of the puzzle"
Supply and Maintenance	In-house, out-house, materials, warranty	"Machines are under warranty"
Personnel Certification	Prior experience, length of time with AM, special certification	"Worked with Honda R&D, design engineer for weapons (CAD and structural analysis)."
Formal Guidance	AFIs, official memorandums, verbal guidance	"Thinks we have polymer process developed, but maintenance applications are far from being developed", "Strategy is lacking; we don't know what we are doing.", "SPO approval and manpower are the biggest hurdles." "Was on the working team to investigate airworthy structural, non-airworthy structural, airworthy non-structural, and non-airworthy non-structural, but we still have no strategy."
Training Program	Trainers, training report, proficiency	"No formal training program, we just need to do it [additive manufacturing] to learn it and get proficient"
Promotion of Key Personnel	Promotions, new hires,	"Have a new engineer coming in, his sole responsibility will be to research AM for practical applications in the depot"
Turnover of Key Personnel	New hires, gaps in personnel, manning	"Currently manned at approx 50% and our sole focus is normal sustainment operations. We can't afford to dedicate time to routinizing a innovation that no one really understands."

Once all the respondent data was analyzed, the researcher summarized all responses and determined whether or not a specific passage and/or cycle had been accomplished.

## Results

### Equipment Turnover

The additive manufacturing equipment currently in use in the organizations under investigation were all procured within the last two years. All respondents indicated they used handheld or free standing scanners in conjunction with computer-aided design to aid in the creation, modification, analysis, or optimization of a design before it is sent to the

specified machine for 3-D printing. Due to the complexity of additive manufacturing and its many potential applications, there are myriad machines and processes used to support the innovation and provide new capabilities. Respondents at one ALC indicated they had a mix of consumer grade FDM and binder-jetting 3-D printing machines. Respondents at the other two ALCs indicated they had industrial grade FDM 3-D printing machines. Respondents at two ALCs also indicated plans to procure DMLS 3-D printing machines within the next fiscal year. Although plans are made to procure machines with new capabilities, respondents indicated there were no formal procedures in place that guided their decision to procure the new equipment. All respondents indicated they wanted to procure the DMLS machine because they felt it was the future (long-term) of additive manufacturing in their organizations, and believed procuring it now would allow them to begin to familiarize themselves and others in their unit with the machine and the DMLS process. Although respondents appear to have the equipment they want, established procedures for acquiring new generations of equipment needed to update the innovation do not exist.

### **Support by Local Funds**

Although respondents were not heavily versed on funding the use and support of additive manufacturing in their respective ALCs, they did indicate they did not have any issues requesting and receiving the necessary materials to maintain and operate their machines and support their research endeavors. Respondents at one ALC were in the process of researching the budgeting process to request additional office space in a new location. The respondents involved in this process indicated the process to request and

justify funding the new office space was the easy part. The process of locating an available space that met their personal requirements as well as requirements for housing sensitive machinery proved to be difficult. Although all respondents perceive funding not to be an issue, it could not be determined if additive manufacturing was supported by the normal budgeting process.

### **Organizational Status**

Currently, the responsibility of overseeing additive manufacturing in the ALCs does not fall on the same unit across the AFSC. It was observed that organizations assigned to support the MRO units with additive manufacturing varied by ALC. In two of the ALCs, the responsibility was assigned to the same organization. In those two ALCs, the respondents indicated they were primarily self-servicing. Their main focus was on using reverse engineering and rapid prototyping to accomplish fit and strength checks on specified components before they were manufactured using traditional means. Respondents at these ALCs also indicated additive manufacturing was only one aspect of their responsibilities. Respondents at one ALC indicated they found it difficult to commit time to researching and developing their organization's additive manufacturing capabilities due to the fact their organization was used as a reactive versus proactive solution with regard to weapons system sustainment.

Respondents at the third ALC indicated they operated more as a for-hire shop, fulfilling requests from other organizations within their ALC and across their base. Their primary focus was rapid prototyping and producing protective equipment such as aircraft throttle covers that were either too expensive to procure from the manufacturer or that the

manufacturer was no longer willing to sell. These respondents also indicated their sole responsibility was to research additive manufacturing and develop practical applications, and that no other activities or responsibilities consumed their time. They also indicated they had excess work capacity; therefore, they actively advertised their capabilities to generate new customers.

### **Supply and Maintenance**

All respondents indicated their equipment was still under warranty. They also indicated they had not experienced any hard breaks with their machines, but if they had, the manufacturer would be responsible for repair. Respondents at one ALC indicated they did have issues with their consumer grade FDM machines due to a minor design defect, but were able to mitigate the defect in-house. All respondents indicated they had no issues obtaining the materials they needed for their machines, but were limited in material selection due to the type of machines they currently had and ongoing research on which materials—composite and strength wise--would be best suited for their projects.

### **Personnel Certification**

Eight out of nine respondents indicated they had been working two years or less with additive manufacturing in their current role and that they had no prior experience with additive manufacturing. One respondent indicated they had prior experience with additive manufacturing when working in the private sector prior to serving in their current capacity. Eight respondents indicated they were career mechanical engineers with one respondent indicating they were a materials engineer. All respondents indicated they did not have to obtain any special certifications to work with additive

manufacturing. They indicated their engineering backgrounds served as the basis for understanding the technical aspects of additive manufacturing. Respondents also indicated that their knowledge was furthered through basic research about the innovation and its capabilities, producing test parts to understand material strength and composition, and attending professional conferences. All respondents indicated their organization had plans to hire additional engineers whose sole purpose would be to research and develop practical applications for additive manufacturing in their respective ALCs. Hiring additional personnel to work with the innovation demonstrates the ALCs commitment to sustaining additive manufacturing in their organizations.

### **Formal Guidance**

All respondents indicated there was no formal guidance that governed their use of additive manufacturing in their respective organization. The lack of formal guidance was due to the fact that additive manufacturing is still in its infancy and much research needs to be done with regards to material strength, material substitutes, and how components, specifically end-use parts, would be tested once developed. Respondents from two ALCs did indicate that although there was no formal guidance established, they had the support of their organizational and base leadership to facilitate research that may one day lead to formal guidance. Respondents indicated another issue with developing formal guidance for this innovation is that there are numerous applications of this innovation with just as many, if not more, material selections. Formal guidance would need to be developed for all applications with all applicable materials and compound materials that detailed the

issues above. Until these uncertainties are answered, standardized procedures cannot be developed.

### **Training Program**

All respondents indicated there was currently no formal training program in place, but machine manufacturers provided training on basic operating procedures. As mentioned in an earlier section, since there is no formal training program, respondents indicated they remained current on the innovation by researching the innovation and the myriad materials that can be used for various projects as well as reading scholarly and practitioner journals. Respondents indicated their organizations provided opportunities for them to attend professional conferences with the DoD and industry to further their knowledge base. Respondents at one ALC did indicate they had plans to provide familiarization training and demonstrate producing test parts, but that they did not receive much interest from the base population. All respondents indicated the constant exposure to research, practicing with the machines, and attending professional conferences sufficed as recurring training.

### **Promotion of Key Personnel**

All respondents indicated they had no knowledge of personnel receiving promotions since using their unit began using this innovation. The lack of personnel promotions can be attributed to the fact that additive manufacturing is a new innovation in the ALCS and SMEs are limited to those currently working with the innovation. Much research remains to be accomplished on additive manufacturing and its myriad practical applications. Removing or promoting personnel further from the source of additive

manufacturing in their organizations at this stage may prove to adversely affect efforts to routinize additive manufacturing.

### **Turnover of Key Personnel**

All respondents indicated that they have not yet lost any personnel since the adoption and implementation of additive manufacturing in their respective organizations. In fact, they indicated their teams have grown. Respondents also indicated additive manufacturing has continued to serve a purpose in their respective organizations since its adoption and implementation.

### **Degree of Routinization**

As mentioned in a previously, Yin (2014) identified three classifications of routinization based on the number of applicable routinization events achieved. Those classifications were poorly routinized, moderately routinized, and highly routinized. Although three passages were found not to be accomplished by any ALC, they were still applicable in determining the degree of routinization. The scale for degree determination is as follows: poorly routinized = 1-3 events accomplished, moderately routinized = 4-6 events accomplished, and highly routinized = 7-9 events accomplished (Yin *et al.*, 1978). Table 6 below depicts how many passages and cycles each ALC accomplished.

As indicated in the table below, although all ALCs did not accomplish the same number of passages and cycles, they did fall within the same degree classification bounds. Therefore, the researcher concluded additive manufacturing is moderately routinized in all three ALCs.

**Table 6: Number of Passages and Cycles Completed per ALC**

	<b>ALC A</b>	<b>ALC B</b>	<b>ALC C</b>
<b>Equipment Turnover</b>			
<b>Support by Local Funds</b>		X	X
<b>Organizational Status</b>		X	X
<b>Supply and Maintenance</b>	X	X	X
<b>Personnel Certification</b>	X	X	X
<b>Formal Guidance</b>			
<b>Training Program</b>	X	X	X
<b>Promotion of Key Personnel</b>			
<b>Turnover of Key Personnel</b>	X	X	X

### **Summary**

This chapter analyzed the data from the interview sample at the AFSC. Each of the nine passages and cycles were discussed from each of the interviewee’s perspective. The questions were directed towards validation of the routinization framework and its applicability to additive manufacturing. Chapter V will summarize the research effort described in the previous chapters. Conclusions and further discussions of analyses are presented. Lastly, recommendations for closing the gaps in the degree of routinization between the ALCs and areas of further research are discussed.

## **V. Conclusions and Recommendations**

### **Overview**

The focus of the research was to answer the following question: “How do individual perceptions of the nine passages and cycles of routinization (equipment turnover, support by local funds, organizational status, supply and maintenance, personnel certification, formal guidance, training program, promotion of key personnel, and turnover of key personnel) relate to an ALC’s degree of the routinization of additive manufacturing?” The accomplishment of nine passages and cycles of routinization were analyzed to determine the degree of the routinization of manufacturing in each of the three ALCs. This chapter first reviews the results of the research and provides conclusions and recommendations for the investigative questions posed in Chapter I. Next, research limitations will be reiterated, followed by opportunities for future research.

### **Results of Research**

The results found in this study were consistent with Yin *et al.*’s (1978) longitudinal study results in that not all innovation routinization passages and cycles are applicable to every innovation as it becomes more routinized, and that the accomplishment of more passages and cycles correlated to a higher degree of innovation routinization. The collected data were analyzed for evidence of the accomplishment of the nine passages and cycles of routinization. From the summarized results presented in Table 3, the researcher concluded that although all three ALCs had not completed the same number of passages and cycles, they did achieve the same degree of the

routinization of additive manufacturing. No ALC achieved the highest degree of routinization. The following section explains these discrepancies by providing conclusions and recommendations to the investigative questions presented in Chapter I.

### **Investigative Question One**

What passages and cycles contributed to determining an ALC's degree of the routinization of additive manufacturing?

Each of the nine passages and cycles of routinization were investigated in each of the ALCs to determine their applicability to the routinization of additive manufacturing. The degree of accomplishment of four passages could not be determined for ALC A, B, and C. Those passages were: equipment turnover, support by local funds, formal guidance, and promotion of key personnel; with there being no evidence of a fifth passage, organizational status, in ALC A. Although there was no evidence of the accomplishment of the above passages, they remained applicable to determining the degree of routinization of additive manufacturing. The lack of a degree of accomplishment of certain passages could be due to the fact that additive manufacturing is still seen as a new innovation, and needs additional time to mature.

### **Investigative Question Two**

What issues prohibited the ALCs from achieving the highest degree of the routinization of additive manufacturing?

The following four issues were applicable to all three ALCs:

The lack of established guidance to procure additive manufacturing equipment could be directly tied to the fact the innovation is not yet supported by formal guidance.

Without established guidelines to govern the applications of additive manufacturing, it makes it difficult to develop procedures for procuring the proper machines to support those applications since specific applications have not yet been determined.

Additionally, expanding the sample population to include personnel that directly work with their organization's budgets could have potentially provided enough data to make a determination on whether or not there was perceived degree of accomplishment of "support by local funds". Additionally, the use of additive manufacturing in the ALCs is still in its infancy; therefore, there may not have been sufficient time for it to be allocated as a budget line.

Furthermore, the researcher concluded from the limited amount of SMEs and use of additive manufacturing, promoting or removing the individuals further from the source of additive manufacturing research and development in their organization would adversely affect their organization's routinization efforts.

Lastly, without formal guidance, the highest level of routinization of additive manufacturing in the ALCs will never be achieved. There are numerous additive manufacturing processes that are best for specific projects. The ALCs should focus their efforts on one particular application, rapid prototyping, and narrow its use to a set number of components. Having a narrower research focus will allow engineers to direct their efforts on fully understanding all aspects of this application for the specified components, including the benefits and limitations. This deeper, focused understanding will provide critical data for the proper authorities to consider for formal guidance development.

In addition to the above issues, ALC A appeared to have its additive manufacturing SMEs in the wrong organization at the time of data collection. ALC A's

respondents indicated they were over worked with daily weapons system sustainment operations and had no time to dedicate to proactive research solutions. An alternative explanation could be that the innovation is in the right organization, the organization may just have the wrong mentality when it comes to weapons system sustainment. The AFSC's objectives were discussed in Chapter 1, and it is leadership's responsibility to ensure their organizational and AFSC objectives align.

### **Investigative Question Three**

What additional influences were found to affect the degree of the routinization of additive manufacturing in the ALCs?

A passage that should be considered in the innovation routinization framework is top management support. This passage would measure the degree to which top management within an organization is supporting or championing an innovation. Top management support could be the distinguishing factor between transitioning a budget to local funds, sustaining qualified personnel to work with the innovation, or keeping the innovation a relevant topic for research and development.

### **Limitations of the Research**

The generalizability of these findings should be viewed with caution since the sample was restricted to three specific ALCs seeking to adopt a specific innovation. Using the same framework for a different innovation, or a different organization seeking to routinize the same innovation may produce different results.

## **Future Research**

Yin *et al.*'s (1978) routinization research provided a framework to study the innovation routinization of various technological innovations in the public and private sector. Studies of this nature could not be found in USAF organizations, therefore, this research attempted to provide a starting point for future USAF innovation routinization research.

The potential for future routinization of additive manufacturing studies exist between the ALCs and the Air Force Research Laboratory (AFRL) to determine if AFRL's research objectives and focus are getting the organizational support they need.

Additionally, narrowing the research focus of additive manufacturing to specific applications could prove beneficial in that it would highlight or eliminate applications initially believed to enhance weapons system sustainment.

Lastly, a gap analysis could be conducted between the USAF and the USN, to determine what additional factors may or may not affect the routinization of additive manufacturing for weapons system sustainment.

## Appendix A: Exemption Request from Human Experimentation Requirements



DEPARTMENT OF THE AIR FORCE  
AIR FORCE INSTITUTE OF TECHNOLOGY  
WRIGHT-PATTERSON AIR FORCE BASE OHIO

23 November 2015

MEMORANDUM FOR Lt Col Matthew A. Douglas, Ph.D.

FROM: Brett J. Borghetti, Ph.D.  
AFIT IRB Exempt Determination Official  
2950 Hobson Way  
Wright-Patterson AFB, OH 45433-7765

SUBJECT: Approval for exemption request from human experimentation requirements (32 CFR 219, DoDD 3216.2 and AFI 40-402) for "Air Force Sustainment Center (AFSC) Way Routinization of Additive Manufacturing Research Study", dated 17 Nov 2015

1. Your request was for exemption based on the Code of Federal Regulations, title 32, part 219, section 101, paragraph (b) (2) Research activities that involve the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior unless: (i) Information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) Any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.
2. Your study **qualifies for this exemption** because you are using interview procedures and are not collecting data which could place the subjects at risk of criminal or civil liability or could reasonably damage the subjects' financial standing, employability, or reputation.
3. This determination pertains only to the Federal, Department of Defense, and Air Force regulations that govern the use of human subjects in research. Further, if a subject's future response reasonably places them at risk of criminal or civil liability or is damaging to their financial standing, employability, or reputation, you are required to file an adverse event report with this office immediately.

11/23/2015

X 

BRETT J. BORGHETTI, Ph.D.  
AFIT Exempt Determination Official

## Appendix B: Research Talking Paper

### TALKING PAPER|

#### ON

#### AIR FORCE SUSTAINMENT CENTER WAY ROUTINIZATION OF ADDITIVE MANUFACTURING RESEARCH PROJECT

- The purpose of this talking paper is to introduce a study being conducted by the Air Force Institute of Technology (AFIT). The purpose of the study is to determine how well the innovation, additive manufacturing, has been routinized into Air Force Sustainment Center (AFSC) organizations and how it is helping those organizations achieve the established AFSC Way objectives.
- Issue / Research Problem Statement
  - In 2012, the AFSC stood up and implemented the “AFSC Way,” a management innovation designed to create a more process-based, efficient organization that fosters a culture of ownership and the application of scientific methodologies and standardized processes to operations.
  - Decision makers at AFSC need to know how its organizations are postured to support new innovations and how the innovations are working in helping them achieve their established objectives.
- Research Objectives
  - Identify the extent to which additive manufacturing has been routinized into a specified organization as compared to the developed framework.
  - Identify how well, and in what situations, the routinization of additive manufacturing has improved AFSC organizations’ ability to meet performance objectives.
  - Identify organizational and/or framework limitations.
- Research Methodology
  - Multiple-case study of Air Logistics Complex units (PMXG, CMXG, etc.)
- Points of Contact
  - Principal Investigator and Researcher, Capt Candis Woods, Graduate Student, AFIT, Department of Operational Sciences
  - Advisor, Lt Col Matthew Douglas, Assistant Professor, AFIT, Department of Operational Sciences
  - Advisor, Lt Col Robert Overstreet, Assistant Professor, AFIT, Department of Operational Sciences
  - Sponsor,

Capt Woods/AFIT/ENS/336-327-9323/caw/4Jan16

## Appendix C: Consent to Participate in Interview

### CONSENT TO PARTICIPATE IN INTERVIEW

#### *ROUTINIZATION OF ADDITIVE MANUFACTURING RESEARCH*

You have been asked to participate in a research study conducted by researchers from the Air Force Institute of Technology (AFIT), Graduate School of Engineering and Management, Department of Operational Sciences. The main objective of the project is to determine how well additive manufacturing has been routinized into your organization as compared to the developed framework. The results of this study will be included in a report and briefing to the AFSC staff, as well as research publications. You were selected as a possible participant in this study because of your knowledge of additive manufacturing in your organization. You should read the information below and ask questions about anything you do not understand before deciding whether or not to participate.

- This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason. I expect that the interview will take 30-60 minutes.
- You will not be compensated for this interview.
- The information you tell us will be kept confidential. All data will be presented at an aggregate level.
- I would like to record this interview so that I can transcribe it and use it for analysis as part of this study. I will not record this interview without your permission. If you grant permission for this conversation to be recorded, you have the right to revoke permission and/or end the interview at any time.
- This project will be completed by January 2016. All interview documents will be stored in a secure work space until 1 year after that date. The documents will then be destroyed.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

(Please initial)

[ ] I give permission for this interview to be recorded and transcribed.

Name of Subject:

Signature of Subject \_\_\_\_\_ Date \_\_\_\_\_

Signature of Investigator \_\_\_\_\_ Date \_\_\_\_\_

Please contact Capt Woods with any questions or concerns at [candis.collins@afit.edu](mailto:candis.collins@afit.edu) or (336) 327-9323.

Capt Woods/AFIT/ENS/336-327-9323/caw/4Jan16

## Appendix D: Interview Questions

### **2015 AFIT AFSC Way Routinization of Additive Manufacturing Study Technician/First Line Supervisor/Supporting Function Interview Script**

1. How were you first introduced to additive manufacturing? Talk to me about your experience with the innovation.
2. How long have you been working with additive manufacturing?
  - a) What type of training program did you go through?
  - b) How was the training administered?
3. How do you remain certified to work with additive manufacturing in your unit?
4. What type of equipment and software do you use for additive manufacturing?
  - a) How has this equipment allowed you to benefit from the capabilities of additive manufacturing?
  - b) What plans (if any) are there to procure additional equipment or software?
5. How is your additive manufacturing support equipment and software maintained?
  - a) What type of inspection schedule does the support equipment and software follow?
  - b) What level is the maintenance accomplished at?
6. How long have you been using additive manufacturing in your unit?
  - a) What official guidance governs the use of additive manufacturing in your unit?
7. What personnel moves have happened as a result of using additive manufacturing in your unit?
  - a) What personnel have been brought in to replace those that left?
  - b) How many new units have you seen stand up as a result of using additive manufacturing?
  - c) What personnel have you lost to other units using additive manufacturing?

8. How has additive manufacturing impacted your unit's manpower?
  - a) What measures are in place to retain qualified individuals to work with additive manufacturing?
  
9. How do you get the equipment you need to support additive manufacturing in your unit?
  
10. What organizations do you primarily see using additive manufacturing?
  - a) What unit do you think should primarily be using additive manufacturing?
  - b) Why do you think the capability should be located there?
  
9. Is there anything else you think I should know to understand how using additive manufacturing will support the objectives of the AFSC Way better?
  
10. Is there anything you would like to ask me?

Thank you for your participation in our study. Please contact me in the future if you come up with any other ideas or would like to clarify the things we talked about today.

**2015 AFIT AFSC Way Routinization of Additive Manufacturing Study  
Group/Squadron Leadership Interview Script**

1. How were you first introduced to additive manufacturing? Talk to me about your experience with the innovation.
  
2. How did you introduce additive manufacturing in your organization?
  - a) Could you describe initiatives/events/activities leading up to the decision to routinize additive manufacturing in your organization?
  - b) What initiative/event/activity was most/least important during the routinization process?
  
3. How did you react to the react to routinization of additive manufacturing in your organization?
  - a) How has your attitude toward routinizing additive manufacturing changed (if at all)?
  - b) In your opinion, what do you think most influences your attitude toward routinizing additive manufacturing?
  
4. How did the work force react to the routinization of additive manufacturing?
  - a) How have the work force's attitudes toward routinizing additive manufacturing changed (if at all)?
  - b) In your opinion, what do you think most influences the work force's attitudes toward routinizing additive manufacturing?
  
5. How do you think the transition has gone?
  - a) How have your duties changed following the routinization of additive manufacturing?
  - b) How much more work do you think there is left to fully routinize additive manufacturing?
  - c) Where do you see your organization in two years, or beyond?
  - d) Describe the organization you hope to be a part of in the future...

6. How has the routinization of additive manufacturing affected your organization (good or bad)?
- a) What positive changes have occurred in your organization since routinizing additive manufacturing?
  - b) What negative changes have occurred in your organization since routinizing additive manufacturing?
  - c) How has your organization changed since routinizing additive manufacturing?
7. Could you describe the role of external organizations in the routinization of additive manufacturing?
8. Could you describe the most important lessons learned from routinizing additive manufacturing?
9. Is there anything else you think I should know to understand routinizing additive manufacturing better?
10. Is there anything you would like to ask me?

Thanks you for your participation in our study. Please contact me in the future if you come up with any other ideas or would like to clarify the things we talked about today.

**2015 AFIT AFSC Way Study**  
***External Organization Interview Script***

1. How were you first introduced to additive manufacturing? Talk to me about your experience with the innovation.
  
2. How has your organization been involved with the routinization of additive manufacturing?
  - a) Could you describe your organization's initiatives/events/activities associated with the routinization of additive manufacturing?
  - b) What initiative/event/activity was most/least important to your organization during the routinization process?
  
3. How did you react to the routinization of additive manufacturing?
  - a) How have your attitudes toward routinizing additive manufacturing changed (if at all)?
  - b) In your opinion, what do you think most influences your attitudes toward routinizing additive manufacturing?
  
4. How did your coworkers react to routinizing additive manufacturing?
  - a) How have your coworkers' attitudes toward routinizing additive manufacturing changed (if at all)?
  - b) In your opinion, what do you think most influences your coworkers' attitudes toward routinizing additive manufacturing?
  
5. How do you think the transition has gone?
  - a) How have your duties changed following the routinization of additive manufacturing?
  - b) How much more work do you think there is left to fully transition?
  - c) Where do you see your organization in two years, or beyond?
  - d) Describe the organization you hope to be working with in the future...
  
6. How has the routinization of additive manufacturing affected your organization (good or bad)?

a) What positive changes have occurred in your organization since routinizing additive manufacturing?

b) What negative changes have occurred in your organization since routinizing additive manufacturing?

7. Could you describe the most important lessons learned from the routinization of additive manufacturing?

8. Is there anything else you think I should know to understand the routinization of additive manufacturing better?

9. Is there anything you would like to ask me?

Thanks you for your participation in our study. Please contact me in the future if you come up with any other ideas or would like to clarify the things we talked about today.

## Appendix E: Objects Produced from AM

Mini catapult produced from FDM



Wrench produced from binder jetting



# Appendix F: Story Board



## Determining the Degree of Routinization of Additive Manufacturing (AM) in the Air Logistics Complexes (ALCs)



**Problem Statement**  
 The potential for enhanced weapons system sustainment through the incorporation of additive manufacturing calls for a critical look at the passages and cycles of innovation routinization.

Co-Advisors: Lt Col Matthew Douglas, PhD and  
 Lt Col Robert Overstreet, PhD  
 Reader: Capt Michael Kreiser, PhD  
 Department of Operational Sciences (ENS)  
 Air Force Institute of Technology

**Results**

- ALC A accomplished 4 of 9 passages and cycles; AM moderately routinized.
- ALCs B and C accomplished 5 of 9 passages and cycles; AM moderately routinized.
- All passages and cycles found to be relevant in degree determination, but degree of relevance dependent upon organizational age of the innovation.
- The lack of the accomplishment of five passages and cycles prevented the ALCs from achieving the highest degree of routinization.
- Top management support was identified as an additional passage that may affect the degree of routinization of future innovations.



**Research Question**  
 How do the ALCs determine their degree of the routinization of additive manufacturing?

**Investigative Questions**  
 Question 1: What passages and cycles contribute to determining an ALC's degree of the routinization of additive manufacturing?  
 Question 2: What issues prohibit the ALCs from achieving the highest degree of the routinization of additive manufacturing?  
 Question 3: What additional factors were found to affect the degree of the routinization of additive manufacturing in the ALCs?

**Analysis**  
 Pattern match to keywords from collected data to theoretical propositions to determine the accomplishment of specific passages and cycles of innovation routinization.

Passage or Cycle	Key Words
Equipment Turnover	Machine type, maintenance, projects, uses
Support by Local Funds	Established budget, budget, funds request process
Supply and Maintenance	In-house, out-house, materials, warranty
Personnel Certification	Prior experience, length of time with AM, special certification
Formal Guidance	AFIs, official memorandums, verbal guidance
Training Program	Trainers, training report, proficiency
Promotion of Key Personnel	Promotions, new hires,
Turnover of Key Personnel	New hires, gaps in personnel, manning

	Equipment Turnover by Local Funds	Organizational Support	Supply & Maintenance	Personnel Certification	Formal Guidance	Training Program of Key Personnel	Promotion of Key Personnel	Turnover of Key Personnel
ALCA			X	X		X		X
ALCB		X	X	X		X		X
ALCC		X	X	X		X		X



**Implications**  
 This study identifies the current degree of the routinization of additive manufacturing in each ALC. The results will serve to guide the ALCs towards the accomplishment of specific passages and cycles that will increase their degree of routinization.

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14. ABSTRACT Fiscal constraints have affected the USAF's spending and sustainment of weapons systems that are being utilized beyond their programmed life cycle; therefore, it is imperative that processes be given the critical eye for improvement, innovative approaches, and/or best practice implementation. The AFSC, part of the AFMC, has embarked on a groundbreaking effort to transform operations and leverage industry best practices, while maintaining focus on warfighter support to create "The AFSC Way." The AFSC Way is based on a shared leadership model that emphasizes speed, safety, and quality, which gives way to innovative ideas and new technologies in order to achieve "Art of the Possible" results, despite fiscal uncertainty. The quest for continued sustainment has led to the recognition of innovation as a vital ingredient for an organization's survival and profitability in this fiscally constrained environment. Additive manufacturing is one such innovation that the AFSC has adopted and implemented in an effort to maintain or enhance current weapons system sustainment practices. If the AFSC is to realize the potential benefits of additive manufacturing, it must be routinized to some degree into the organization's governance systems. This research seeks to aid in increasing the understanding of what routinization events affect an innovation's degree of routinization.				
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