chapter three

Comprehensive project management of high-end additive manufacturing equipment

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Project management for additive manufacturing (PM-4-AM) is the premise of this chapter. The chapter presents a comprehensive project management approach for installing high-end additive manufacturing (AM) equipment. The core of the comprehensive model is the Triple C model of project management, which presents a systematic structure for communication, cooperation, and coordination across high-tech assets. Like all advanced manufacturing endeavors, the funding, purchase, installation, maintenance, utilization, and decommissioning of high-end AM equipment requires strategic implementation of project management techniques. The level of communication, cooperation, and coordination required for effective acquisition adoption of AM can be facilitated and enhanced by comprehensive project management practices from a system’s perspective.

3.1 Introduction

AM (also known as 3D printing or direct digital manufacturing) is quickly emerging as the new technology of choice in manufacturing. The new global business model necessitates that products have to be developed across geographically disparate regions. This creates new challenges for the technical and managerial aspects of developing new products. For a product to be competitive in the new market place, its design process must be agile and adaptable to the changing environment. AM makes this possible. However,
this new technological tool must be managed just like any conventional project. A comprehensive project management approach (Badiru and Pulat, 1995) holds good promise for enhancing the adoption of AM.

Badiru (2012) defines project management as the process of managing, allocating, and timing resources in order to achieve a given objective in an expeditious manner. The objective may be in terms of time, monetary, or technical results. Project management is the process of achieving objectives by utilizing the combined capabilities of available resources. It represents a systematic execution of tasks needed to achieve project objectives. In a new technology environment, the basic functions of project management cover the following:

1. Planning
2. Organizing
3. Scheduling
4. Control

Because of the complexity often encountered when installing new high-tech equipment, the steps of the design process require thinking outside of the conventional project box. It has been shown again and again that the majority of technology failures can be traced to communication failures at the initial stages of a project. Thus, communication constitutes an important foundation for achieving success in AM technology projects. When embarking on the purchase, installation, and utilization of high-end AM equipment, some of the issues of crucial consideration include the following:

- Purchasing process and contracting requirement
- Delivery timeline
- Safety concerns
- Training requirements
- Maintenance
- Skilled operators
- Service contract
- Space requirements (equipment footprint and supporting infrastructure)
- Power supply
- Water needs
- Heating, ventilation and air conditioning (HVAC) needs
- Operational requirements
- Occupational safety and health administration (OSHA) requirements
- Sustained utilization
- Funding (initial and subsequent)
- Vibration control
- Facilities upkeep (housekeeping around equipment)
- Production level requirements
- Minimum acceptable quality

All of these, and some more not listed here, require a whole lot of coordinated project management. Essentially, a comprehensive project management is required.
3.2 Basics of the Triple C model for additive manufacturing project management

The Triple C model introduced by (Badiru, 2008) is an effective project-planning tool that has been successfully utilized for projects of all types. It can be particularly effective for a distributed product development environment, such as AM, where personnel coordination is very crucial. The model states that project management can be enhanced by implementing it within the integrated functions of

- Communication
- Cooperation
- Coordination

The Triple C model facilitates a systematic approach to planning, organizing, scheduling, and control. The model is shown graphically in Figure 3.1. It highlights what must be done and when. It can also help to identify the resources, such as personnel, peripheral equipment, facilities, power supply, and space requirements, associated with the AM equipment.

Typical questions to be addressed in PM-4-AM include the following:

Who: Who is the point of contact for the new equipment? Who made the selection? Who else is involved? Who has been informed? Who will run the equipment? Who are the users? Who will maintain the equipment? Who is proving the funding for all the needs affiliated with the equipment?

What: What is being purchased? What will the equipment be used for? What are the options? What will be equipment replace or supplement? What peripheral installation needs are involved? Safety concerns? Security concerns? Power supply needs?

![Figure 3.1 Triple C project management framework for additive manufacturing.](image-url)

**Which:** Which functional and/or administrative units are responsible for the equipment?

**When:** When will the equipment be purchased? When is the delivery timeline? When is the contracting timeline, if applicable?

**Where:** Where will the equipment be placed? Is colocation with other organization facilities possible?

**How:** How will the equipment be used? How will the equipment be maintained? How will the equipment utilization be sustained? How will the equipment be decommissioned, when applicable?

**Why:** Why is the equipment needed at all?

### 3.3 Communication

Communication facilitates team work. The communication function of project management involves making all those concerned become aware of project requirements and progress. Those who will be affected by the project directly or indirectly, as direct participants or as beneficiaries, should be informed regarding the following:

- Scope of the product
- Personnel contribution required
- Expected cost and merits of the project
- Project organization and implementation plan
- Potential adverse effects if the project should fail
- Alternatives, if any, for achieving the project goal
- Potential direct and indirect benefits of the product development project

The communication channel must be kept open throughout the project life cycle. In addition to internal communication, appropriate external sources should also be consulted. This is particularly essential for a distributed product design environment where design participants may be geographically dispersed over large distances. **Figure 3.2** presents a specific application to intermodule communication in AM product development.

![Figure 3.2 AM product intermodule communication channels.](Image)
Using Triple C helps to clarify the following questions, particularly when the modules are designed at geographically dispersed locations:

- Does each product development participant know what the objective is?
- Does each product development participant know his or her role in achieving the objective?
- What obstacles may prevent a participant from playing his or her role effectively?

Some of the sources of communication problems for high-tech technology project management are summarized below:

**Social environment:** Communication problems sometimes arise because people have been conditioned by their prevailing social environment to interpret certain issues in unique ways, particularly when new pieces of technological equipment are being contemplated. Vocabulary, idioms, organizational status, social stereotypes, and economic situation are among the social factors that can impede effective communication in advanced manufacturing organizations. AM is not immune to these adverse scenarios.

**Cultural background:** Cultural differences are among the most pervasive barriers to technological project communications, especially in today’s multinational organizations. Language and cultural idiosyncrasies often determine how communication is approached, received, and interpreted.

**Semantic and syntactic factors:** Semantic and syntactic barriers to communications usually occur in written documents. Semantic factors are those that relate to the intrinsic knowledge of the subject of the communication. Syntactic factors are those that relate to the form in which the communication is presented. The problems created by these factors become acute in situations where response, feedback, or reaction to the communication cannot be observed directly or face-to-face. Explicit efforts must be made to bring everybody on board for AM equipment installation.

**Organizational structure:** Frequently, the organization structure within which a technical project is housed has a direct influence on the flow of information and, consequently, on the effectiveness of communication. Organization hierarchy may determine how different personnel levels perceive specific information. One key aspect to keep in mind is the proverbial guide of the higher the level of management, the lower the level of details needed. An overly technical presentation of an AM project can quickly lose the interest of management. This is particularly important where funding decisions are involved.

**Communication medium:** The method of transmitting a message may also affect the value ascribed to the message and, consequently, how it is interpreted or used. With the excessive prevalent of e-mail communications nowadays, it is essential to determine where and when direct face-to-face communication is better than email transmission of critical information about a proposed AM equipment.

**Figure 3.3** shows a condensed sample of multidimensional communication matrix for AM environment. Actual users will include all the pertinent elements for their specific operating environment. Communication across various functional lines is important to bring everyone on board for a cohesive AM effort. Of particular importance is the need to keep end-user requirements in mind throughout the development process. The cells in the communication matrix indicate the source-to-target communication linkages as well as specific topic of communication. This helps to identify not only who is communicating with whom, but also what is expected to be communicated.
Cooperation of the personnel involved in AM must be elicited using explicit means. Merely, voicing consent for a project is not an enough assurance of full cooperation. Participants and beneficiaries of the project must be convinced of the merits of the project. The pros and cons should be addressed. Never shy away from the cons of a project. Rather than being a source of ire for team members, a specification of the cons may be vital for garnering support, as long as individuals know what to expect and what not to expect. Some of the factors that influence cooperation in a project environment include personnel requirements, resource requirements, budget limitations, past experiences, conflicting priorities, space limitation, resource-sharing constraints, and lack of uniform organizational support. A structured approach to seeking cooperation for AM should clarify the following:

- The level and type of cooperative efforts required
- Precedents for collaborative projects
- The possible implication of lack of cooperation
- The criticality of cooperation to project success
- The expected organizational impact of cooperation
- The time frame involved in the project
- The organizational benefits of cooperation
- The personal benefits or rewards of cooperation

The types of cooperation required for a successful product development include functional cooperation, social cooperation, legal cooperation, administrative cooperation, proximity cooperation, dependency cooperation, lateral cooperation, vertical cooperation, and imposed cooperation. Some of these are possible only in certain types of project scenarios. Below are some guidelines for securing cooperation for AM:

- Establish achievable goals for the project.
- Clearly outline individual commitments required.
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- Integrate project priorities with existing priorities.
- Allay the fear of job loss due to AM products compared to traditional manufacturing.
- Anticipate and preempt potential sources of resource conflicts.
- Remove skepticism by referring to earlier communication of the merits of the project.

3.5 Coordination

After communication and cooperation functions have been initiated successfully, the efforts of the project personnel must be coordinated. Many projects fail because the project team anxiously jumps to the coordination stage. But where there has not been sufficient communication and there is a lack of cooperation, coordination cannot be accomplished effectively. Coordination facilitates congruent organization of efforts. The construction of a responsibility chart can be very helpful at this stage. A responsibility chart is a matrix consisting of columns of individual or functional departments and rows of required actions. Cells within the matrix are filled with relationship codes that indicate who is responsible for what. The matrix helps to avoid neglecting crucial communication requirements and obligations. It helps resolve questions such as:

- Who is to do what?
- How long will it take?
- Who is to inform whom of what?
- Whose approval is needed for what?
- Who is responsible for which results?
- What personnel interfaces are required?
- What support is needed from whom and when?

When implemented as an integrated process, the Triple C model can help avoid conflicts in new high-end equipment installation. When conflicts do develop, it can help in resolving the conflicts. Several sources of conflicts can exist in complex technical projects, including the following:

Schedule conflict: Conflicts can develop because of improper timing or sequencing of project tasks. This is particularly common in large multiple projects spread over multiple locations. Procrastination can lead to having too much to do at once, thereby creating a clash of project functions and discord among team members. Inaccurate estimates of time requirements may also lead to infeasible activity schedules.

Cost conflict: Product development cost may not be generally acceptable to the clients of a project. This will lead to project conflicts. Even if the initial cost of the product development is acceptable, a lack of cost control during implementation can lead to conflicts. Poor budget allocation approaches and the lack of a financial feasibility study will cause cost conflicts later in the product development process. One area of concern for AM is the cost of supplies to sustain the operation of the AM equipment. Adequately funding the purchase of AM equipment is one thing, but funding the recurring purchase of supplies is an entirely different thing.
Performance conflict: If clear performance requirements are not established, AM product performance conflicts will develop. Lack of clearly defined quality standards and expectations can lead each person to evaluate his or her own performance based on personal value judgments. In order to uniformly evaluate quality of AM outputs and monitor project progress, performance standards should be established based on the intended scope of the AM project.

Management conflict: There must be a two-way alliance between management and the AM team. The views of management should be understood by the team. The views of the team should be appreciated by management. If this does not happen, management conflicts will develop.

Technical conflict: If the technical basis of a project is not sound, technical conflicts will develop. New manufacturing projects are particularly prone to technical conflicts because of their significant dependence on technology. Lack of a comprehensive technical feasibility study will lead to technical conflicts. AM is relatively new in industrial practice. Consequently, many technical issues remain to be ironed out. Clear communication, solid cooperation, and tight coordination can help defuse the adverse impacts of technical conflicts.

Priority conflict: Priority conflicts can develop if project objectives are not defined properly and applied uniformly across a project. A lack of a direct project definition can lead each project member to define his or her own goals which may be in conflict with the intended goal of the project. A lack of consistency of the project mission is another potential source of priority conflicts. Over-assignment of responsibilities with no guidelines for relative significance levels can also lead to priority conflicts. One person taking on the task of what should be a team effort is a sure basis for priority conflict. Again, using the Triple C model can help preempt or resolve priority conflicts.

Resource conflict: Resource allocation problems are a major source of conflicts in any project management. Competition for resources, including personnel, tools, hardware, software, space, and so on, can lead to disruptive conflicts.

Power conflict: Project politics lead to a power play which can adversely affect the progress of a project. Project authority and project power should be clearly delineated. Project authority is the control that a person has by virtue of his or her functional position. Project power relates to the clout and influence, which a person can exercise due to connections within the administrative structure of an organization. People with popular personalities can often wield a lot of project power in spite of low or nonexistent project authority.

Personality conflict: Personality conflict is a common problem in projects involving a large group of people. The larger the project, the larger the size of the management team needed to keep things running. Unfortunately, the larger management team creates an opportunity for personality conflicts. Communication and cooperation can help defuse personality conflicts.

3.6 Distributed additive manufacturing product development

This section covers the fundamentals of distributed product development in AM. Figure 3.4 presents the product development process in a distributed environment across functional areas. The inputs are in terms of capital, raw material, and labor. At the
output end, the physical products are complemented by organizational services and a metric of market share. The project management approach embodies technology, people, and work process. In this environment, the Triple C model serves as the tool to integrate the various project management efforts.

3.7 Analysis of additive manufacturing project requirements

A typical project is undertaken to create a unique product, service, or result. In the case of AM, the project output is a certain product, hopefully of high quality, that meets the market needs of the organization. The key to getting everyone on board with the AM process is to ensure that product objectives are clear and comply with the principle of SMART as outlined below:

- **Specific**: Task objective must be specific. Project objectives must be specific, explicit, and unambiguous. Objectives that are not specific are subject to misinterpretations and misuse.
- **Measurable**: Task objective must be measurable. Project objectives should be designed to be measurable. Any factor that cannot be measured cannot be tracked, evaluated, or controlled.
- **Aligned**: Task objective must be achievable and aligned with overall project goal.
- **Realistic**: Task objective must be realistic and relevant to the organization. A project’s goals and objectives must be aligned with the core strategy of an organization and relevant to prevailing needs. If not aligned, an objective will have misplaced impacts. A project and its essential elements must be realistic and achievable. It is good to dream and have lofty ideas of what can be achieved. But if those pursuits are not realistic, a project will just end up spinning wheels without any significant achievements.
- **Timed**: Task objective must have a time basis. Timing is the standardized basis for work accomplishment. If project expectations are not normalized against time, there will be no basis for an accurate assessment of performance.

If a task has the above intrinsic characteristics, then the function of communicating the task will more likely lead to personnel cooperation. A SMART approach to developing and communicating AM objectives can ensure the cooperation of everyone. Specific means that an observable action, behavior, or achievement is described. It also means that the work links to a rate of performance, frequency, percentage, or other quantifiable measure. For some jobs, being specific can, itself, be nebulous. However, to whatever extent possible and reasonable, we should try to achieve specificity. That is exactly what project management seeks to achieve. This ensures that the leadership team, operators, staff, and customers all share the same expectations.

The word *measurable* means observable or verifiable, which implies that a method or procedure must be in place to track and assess the behavior or action on which the objective focuses and the quality of the outcome. As not all work lends itself to measurability, objectives can be written in a way that focuses on observable or verifiable behavior or results, rather than on measurable results. If no measurement system exists, the project manager must be able to monitor performance to ensure that it complies with the specified objective.

An aligned objective provides a conceptual basis to draw a linkage line from the objective to other factors throughout the project. It means that the objectives throughout the organization pull in the same direction. In this way, the performance of the project team and whole organization is improved.

Project managers must have a clear understanding of their own objectives before they can work with project team members to establish their job objectives. This is one of the key building blocks of performance assessment in project management. If managers know the functions on which people actually are spending time, they can make meaningful improvements in organizational performance by ensuring effort is focused on work that is valued by the organization and by eliminating inefficient processes. Job objectives align work with organizational goals and the mission, drawing the line of sight between the employee’s work, the work unit’s goals, the project functions, and the organization’s success. The letter “R” in SMART has two meanings that are both important: realistic and relevant.

*Realistic has two meanings:*

- The achievement of an objective is something an employee or a team can do that will support a work unit’s goal. The objective should be sufficiently complex to challenge the individual or team but not so complex that it cannot be accomplished. At the same time, it should not be so easy that it does not bring value to the individual or the team.
- The objective should be achievable within the time and resources available to the project, which is usually expressed as triple constraints of time, cost, and quality.

Relevant implies that it is important for the advancement of the employee and the organization.

*Figure 3.5* illustrates the application of the Triple C approach of project management in the context of using the SMART principle of project performance assessment.
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3.8 Conclusion

This chapter has presented general principles of project management and applicability to AM. The knowledge areas compiled by the Project Management Institute (PMI) are generally applicable to the theme of this chapter. Readers are encouraged to seek more in-depth techniques of project management within the specific knowledge areas listed below, based on PMI's project management body of knowledge (PMBOK®):

1. Project integration management
2. Project scope management
3. Project time management
4. Project cost management
5. Project quality management
6. Project human resource management
7. Project communications management
8. Project risk management
9. Project procurement management

The above segments of the body of knowledge of project management cover the range of functions associated with any project, particularly complex ones, such as AM. Multinational projects particularly pose unique challenges pertaining to reliable power supply, efficient communication systems, credible government support, dependable procurement processes, consistent availability of technology, progressive industrial climate, trustworthy risk mitigation infrastructure, regular supply of skilled labor, uniform focus on quality of work, global consciousness, hassle-free bureaucratic processes, coherent safety and security system, steady law and order, unflinching focus on customer satisfaction, and fair labor relations. Assessing and resolving concerns about these issues in a step-by-step fashion will create a foundation of success for a large project. Although no system can be perfect and satisfactory in all aspects, a tolerable trade-off on the factors is essential for project success. That is what this chapter advocates for new endeavors of AM.
References

Badiru, Adedeji B. (2008), Triple C Model of Project Management: Communication, Cooperation, and Coordination, CRC Press/Taylor & Francis, Boca Raton, FL.
