A General Detector Systems Integration Model

A SYSTEMS ENGINEERING APPROACH TO INTEGRATING EXPERIMENTAL SYSTEMS

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ABSTRACT

The document examines the need for a coordinated integration plan when performing the design and installation of experimental particle detection systems. A model is described which views the integration process in five phases; system definition, system design, integration planning, fabrication & assembly, and installation. For each integration phase, a sequence of steps is identified, each of which generates, updates or maintains the system of documentation that informs the integration process.

INTRODUCTION

The objective of system integration is to coordinate the *interfaces, interferences,* and *interactions* between the sub-systems and their environment to achieve operability. For the purpose of this definition, *interfaces* are all of the connections and conduits (input/output) between a sub-system and other entities, *interferences* are the limiting factors within the assembled system (and its environment) that constrain the sub-systems, and *interactions* are the emergent conditions that arise from the operation (or coexistence) of multiple sub-systems in the operating environment. The job of the system integrator is to continuously monitor and assess all of these factors throughout the development, implementation, and installation processes, while keeping a keen eye to identify and eliminate conflicts as they emerge.

Limiting the Model's Scope

In reviewing this model, the reader should keep in mind a clear distinction between the system designer and the system integrator. The system (or sub-system) designers are expert within their specific domain. It is their responsibility to know everything that they can about their system, how it operates and what it needs in terms of resources. There are many different sub-systems within a detector package – all of which require individuals with different expertise. The role of the system integrator is to have a cross-cutting understanding of how all of the sub-systems work together to achieve operability, and to maintain constant communication as the sub-systems evolve during the integration process. The integrator must identify and continuously monitor a collection of key data points from within each sub-system and identify variances that will impact system viability. Because the number of data points in each sub-system is vast, system integrators must purposely limit their scope to a finite set.

Therefore, while system designers must know ***everything*** *they can about their sub-system, system integrators should know* ***as little as necessary*** *to integrate the entire system.* This commends a system integration model that is as lightweight as possible, while still addressing those factors that impact interoperability.

The model described here defines a minimal subset of information that the system integrator must collect and maintain to ensure successful system integration. In reviewing this approach, readers who are system experts will naturally be inclined to want to add new elements which they view as critical from their perspective. While this model is by no means final, each addition adds complexity. Therefore, the revisor should always ask, *"Does the system integrator really need to know this?"* before expanding the model.

Likewise, the model defines a collection of documents that are generated and maintained throughout the integration lifecycle. The number of documents produced has been purposely minimized, such that each document has a well-defined role within the integration process. Beyond the scope of system integration, there are any number of additional documents that must be created to comply with regulatory requirements or local policies… and there will be a temptation to integrate them into this model. System integrators should resist the urge to add new documentation requirements to the model unless they specifically *(and directly)* contribute to the integration process. As an alternative, supplemental information should be integrated into the already defined documents; allowing them to serve as a conduit for other reports.

General Structure of the Model

The detector systems integration model is divided into five major processes: *system definition, system design, integration planning, fabrication & assembly,* and *installation*. Each of these processes has a distinct set of functions that must be performed and documents that should be generated. The model is composed of a collection of interconnected nodes that represent activities, and a system of arrows illustrating the work-flow. Figure 1 shows two connected nodes from the *system definition* process.

The node labeled *'Identify Autonomous Sub-systems'* is a general function node and represents an activity that must be performed in the integration process. A general function node may or may not have contributing activities.

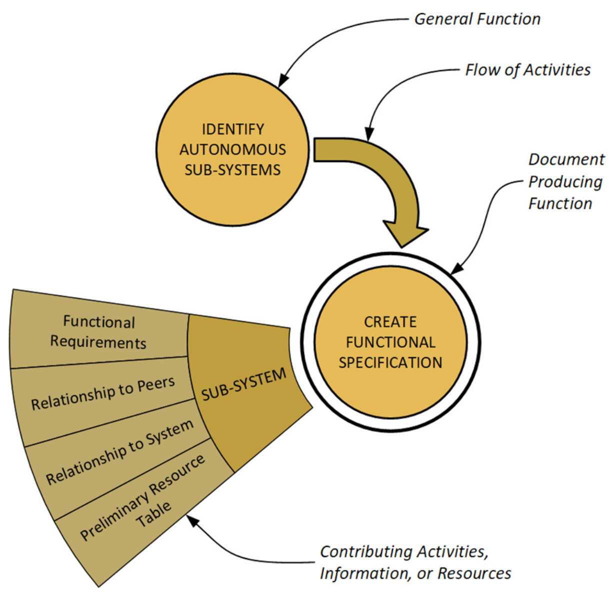

Figure 1. Features of the Integration Model

The node labeled *'Create Functional Specification'* is a document producing node, meaning that at the completion of this function, a document, report or other data set will be generated. In this example, the node is connected to a *fan-shaped* block containing an array of activities, information or resources that are associated with the main function.

The two nodes are joined by an arrow that represents the flow of activity through the model. In general, this model flows from *top-to-bottom* and from *left-to-right*.

The balance of this document will describe each of the major processes and the activities that occur within them. The timing and rational for the flow between activities will also be described, as well as the *iterative loops* that occur in several of the process trees. While providing specific examples of the documents that are generated by these activities is beyond the scope of this paper, a brief description of their purpose will be provided – along with a clear justification for their inclusion.

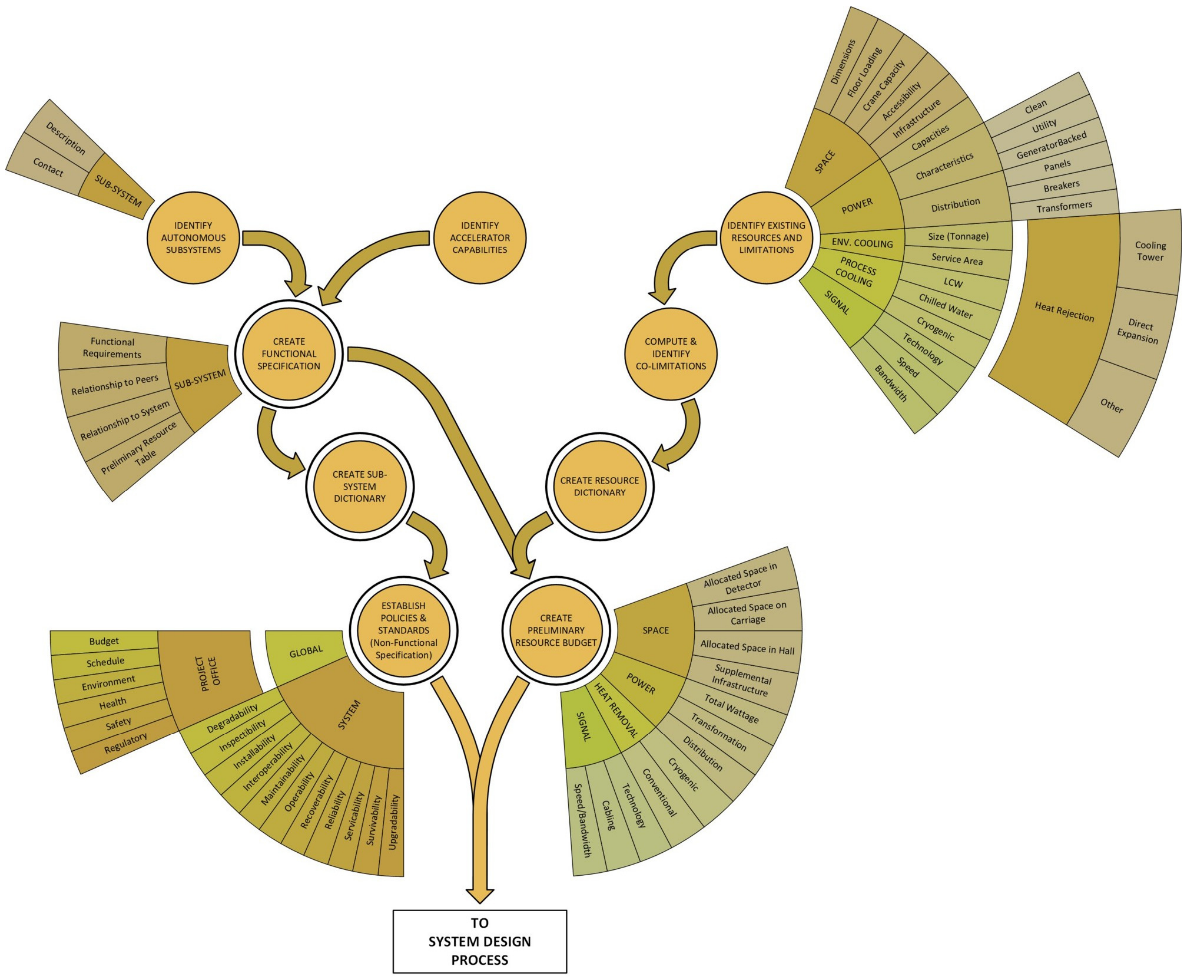

Figure 2. The System Definition Process

THE SYSTEM DEFINITION PROCESS

System definition is the first major process in the integration model and it proceeds along two paths: system identification and resource identification.

On the ***system identification track***, all of the sub-systems are identified and specifications are developed that clearly state what functions they will perform and how they will interact with other sub-systems, the facility and their environment. System-wide policies and standards are also established that dictate the performance levels that will be expected of each sub-system and the global standards that they are expected to meet.

On the ***resource identification track***, a working inventory of available resources is developed and documented. Based on the early estimates from the sub-systems, a preliminary resource budget is created that details how these resources will be shared across the system.

The following sections describes the individual functions within the system definition process, how they should be executed, and the documentation that should be generated.

System Identification Track

- **Identify Autonomous Sub-Systems**
  In this function a complete inventory of autonomous sub-systems is developed. An autonomous sub-system is a high-level entity with a defined function which is performed independently of other sub-systems and whose design and implementation is conducted separately from its peers.

  The cataloging of sub-systems accomplishes several purposes. First, it forces the design team to determine which sub-systems should operate independently and which should be aggregated into larger groups. Secondly, it creates an index of sub-systems – each of which has a point of contact and a preliminary description of its purpose. Finally, it serves as an *attendance sheet* for future functions, to ensure that all sub-systems have been accounted for in the planning process.

- **Identify Accelerator Capabilities**
  In order to design the detector sub-systems, certain assumptions have to be made about the qualities and characteristics of the accelerator. Here, the expected accelerator performance standards are quantified and agreed on by stakeholders from both the accelerator and detector sides. The capabilities documented here will inform the development of the functional specification for the detector sub-systems and will serve as a baseline for future decisions.

- **Create the Functional Specification**
  The functional specification is a foundational document for the entire system integration process. It describes exactly what functions a sub-system must perform and the performance standards that must be met. For each sub-system, this document describes its position and its relationships relative to its peers and the system as a whole. It identifies the interfaces and interconnections that will link each sub-system, and it provides a preliminary list of resources that each sub-system will require.

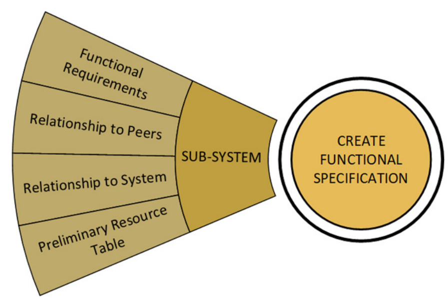

Figure 3. Create the Functional Specification

  Designers from outside of the sub-system should be able to rely on the functional specification as the definitive source for how a sub-system will behave, its required inputs, and its expected outputs. Of equal importance, the functional specification serves as the baseline for evaluating potential changes during system design. Any proposed change must be evaluated to determine if it impacts how well the sub-system satisfies its functional requirements, and whether it alters the inputs or outputs that peer sub-systems are relying on.

- **Create Sub-System Dictionary**
  The sub-system dictionary is a catalog of sub-systems which provides an abstract of their functions, resource requirements, relationships and interconnections as identified in each of their functional specifications. It is an early model of the system that provides a fundamental *(and compact)* description of how the system is built and the dependencies that exist within it.

- **Establish Policies and Standards**
  Beyond the functional specification, there are many non-functional requirements that are essential to system design and implementation. These are captured in the policies and standards for system design. These policies fall into two general categories; system and global.

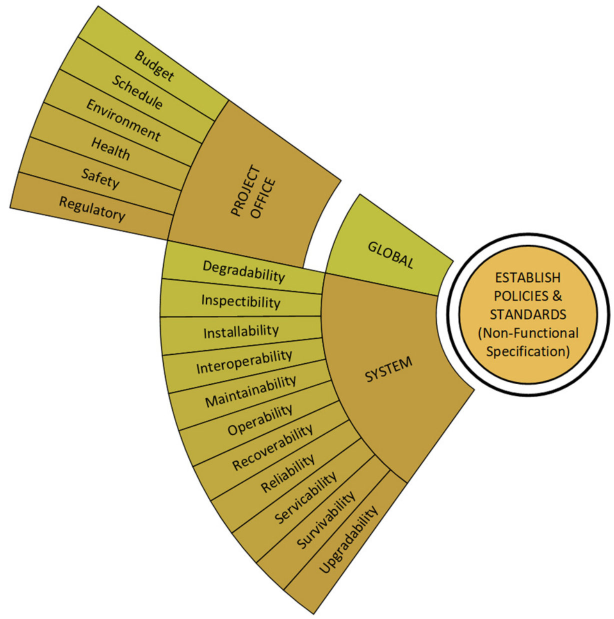

Figure 4. Establish Policies & Standards

System Standards

System standards are factors that are part of traditional systems engineering. They assess the criticality of each sub-system with regard to overall system performance, and then identify specific steps that can be taken to help ensure operational success.

Over the years, more than 100 non-functional factors have been documented. This model identifies a few of the most pertinent ones, but others should be included if they are beneficial. The following are some key factors:

Degradability: the capacity of the sub-system to continue to operate in a degraded state.

Inspectibility: how accessible the sub-system is for inspection of components and interfaces.

Installability: factors and issues that impact the installation of the sub-system and its components.

Interoperability: the capacity of the sub-system to connect and interact with its peers and the larger system.

Maintainability: the relative ease with which the sub-system can be retained in, or restored to, normal operation.

Operability: the overall capacity of a sub-system to remain operational during its lifecycle.

Recoverability: the ability of the sub-system to recover, with minimal intervention, following a failure.

Reliability: the use of redundant paths or components to minimize the likelihood of a sub-system's failure.

Serviceability: how well the sub-system accommodates preventive and corrective maintenance. *Note: systems with low maintainability/ serviceability must have increased reliability.*

Survivability: the ability of a sub-system to minimize the impact of a finite disturbance on its performance.

Upgradability: the capacity of the sub-system to be upgraded.

Global/Organizational Policies & Standards

This collection of policies and standards is more detached from the operational aspects of the sub-systems, but is no less important. These include things like regulatory requirements, project level budgets and scheduling, and environmental, health and safety compliance. As with system designers, the management of these policies requires specific expertise, which should be separated from the system integration function.

In this model, these functions are facilitated through the project office. This allows top-level project staff to tailor policy requirements to satisfy their intended goals, while still balancing those requirements against the objectives of the project.

Resource Identification Track

Resource identification is the second track of the system definition process. During these activities, the system integration team will identify all resources that will be available for the installed system and will identify any limitations or constraints that will govern their usage.

Note that during the system definition process, only the resources that are required ***FOR OPERATIONS*** *are assessed. Additional resources that will be needed for staging, fabrication, assembly and installation are calculated later, in the logistics planning process.*

- **Identify Existing Resources**
  While many types of resources are required for detector operation, some of the most common are space, power, cooling and signal. This section discusses the general considerations that are involved in assessing these resources.

Figure 5. Identify Existing Resources

Space

Space assessment requires that the system integrator examine all of the characteristics of the facility where the system will operate. More than merely dimensions, this assessment considers and documents floor loading, crane capacity, accessibility issues *(such as door heights)* and the availability of supporting infrastructure.

Power

Provisioning power for the detector and its sub-systems requires the integrator to look beyond mere wattage, and examine a variety of electrical characteristics, including:

Capacities

In assessing power resources, begin by determining the available size of the electrical service (or services) that are delivering power to the operating area. It is essential to begin this process as far up-stream of the operating areas as practical, to determine how much power is being diverted to other operational areas and how much is available for use. Keep in mind that breaker sizes dictate the maximum amount of power that can be delivered downstream; the available power may be much less.

Characteristics

The characteristics of the power should be assessed next. Power that is isolated through a transformer for use by sensitive electronics (clean power) should be cataloged separately from the power that is used to operate cranes and electrical motors (utility power). Further, if UPS or generator-backed power (emergency power) is provided, it should be listed separately as well.

Emergency power is treated distinctly for two main reasons:

1) emergency power is a limited resource and should only be allocated to sub-systems that have a well-defined need, and

2) the heat produced by system using emergency power continues to be generated during a power outage; requiring an alternate cooling strategy to be identified.

Distribution

Finally, the distribution of power within the facility is assessed. This includes the locations and capacities of switchboards and panels, the breaker capacity within the existing panels, and the size and locations of transformers and power supplies. Power distribution within an experimental facility is frequently altered to satisfy the demands of the equipment. This assessment gives the system integrator and early idea of what is currently available and what will need to be demolished, installed or modified to support the system.

Environmental Cooling

Environmental cooling is typically provided by traditional HVAC systems. These maintain the air temperature in the facility (or a specific area) at a predefined level and reject the heat to a cooling tower, direct expansion heat exchanger, or other system. Environmental cooling is used to ensure a safe operating temperature for workers, to keep active and passive detector systems within a safe operating threshold, and to remove heat from systems that are not directly attached to process cooling.

Process Cooling

Process cooling may come in the form of chilled water, low conductivity water (LCW) or cryogenic liquids and gases. These systems are used for bulk heat removal from targeted locations. Much like environmental cooling, they must reject their heat to another medium that is outside of the operating area.

Heat Rejection

While heat rejection systems are tightly coupled to environmental and process cooling, they are a shared commodity and should be evaluated independently. A single cooling tower may provide heat rejection for the environmental cooling systems, as well as for process cooling such as chillers and LCW systems. As a result, the cooling capacity of a facility may not be limited by the size of the air conditioners or water systems, but by the total capacity of the cooling towers that service them.

Signal and Communication

Finally, signal and communications resources are the communications media that carry information in and out of the operating area. The availability of these resources is defined by the size and capacity of the switching systems, the size and capacity of the upstream data lines that service the switches, and the number and type of transmission lines that are distributed within the operating area. The nominal data rates of all media should be documented, as should the bandwidth that will be available for use when the detector system is deployed.

- **Identify Co-Limitations**
  Resource co-limitations occur when the usability of one resource is dictated by the availability of another. The most common example of this is the relationship between power and cooling. Every watt of power

that is consumed within an enclosed area must be offset by 3.41 BTUs of cooling capacity. As a result, the amount of electrical power that can be consumed by a system is always limited by the amount of heat rejection capacity that is available.

The goal of this activity is to examine all of the resource dependencies and identify bottlenecks that limit their actual capacity.

- **Create the Resource Dictionary**
  Similar to the sub-system dictionary, the resource dictionary is a document that catalogs all of the resources that were identified in the prior steps and any co-limitations that exist between them. This document provides the foundation for creating the preliminary resource budget for the sub-systems.

- **Create the Preliminary Resource Budget**
  The final step of the system definition process is to develop a preliminary resource budget using the sub-system and resource dictionaries. This document provides an initial estimate of the total amount of operational resources that are required and how they will be allocated to the sub-systems.

  While the allocations defined here are preliminary, they do provide early design parameters for the sub-system experts to use in developing their components. Additionally, the preliminary resource budget is also beneficial for identifying potential resource short-falls that will need to be resolved before the system can begin operation.

  As the system integration processes proceed, the preliminary resource budget will serve as the foundation for two key integration documents: the integrated space plan and the integrated resource plan.

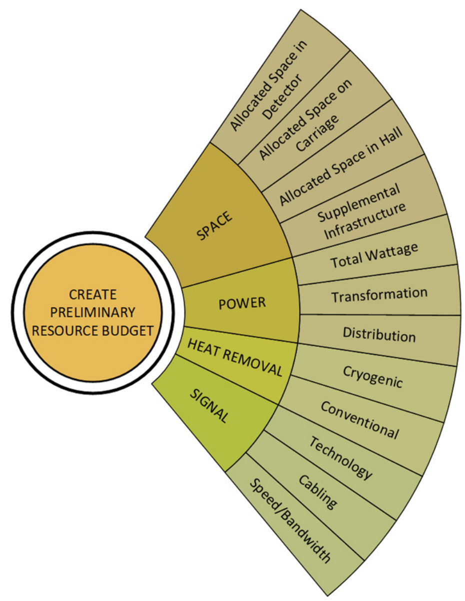

Figure 6. Create the Preliminary Resource Budget

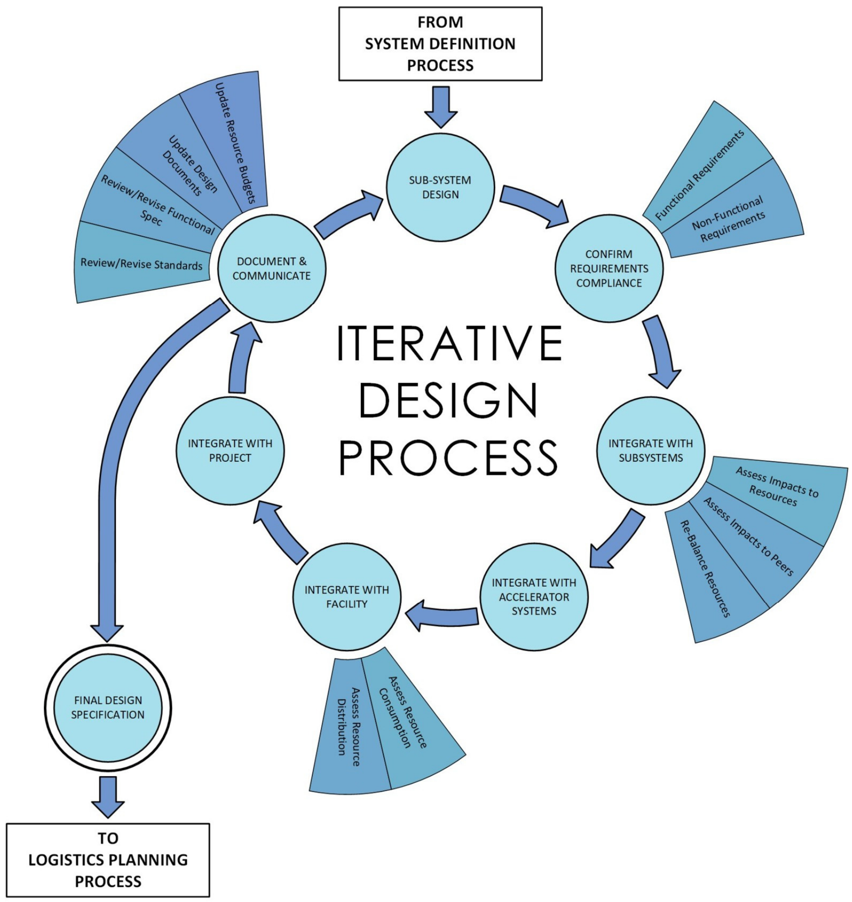

Figure 7. The System Design Process

SYSTEM DESIGN

The goal of the system design process is to transform the functional specification and the system standards into a final design specification that can be used to build the system. The design process is manifested as an iterative loop where individual sub-system are designed independently and then are integrated across several steps to ensure they meet their functional requirements and can operate properly within the larger system and the facility.

The Iterative Design Process

The iterative design loop is a sequence of steps that begins with system design, followed by evaluation and integration, and ends with documentation. The process repeats for each sub-system until a compliant design is produced that meets performance and policy standards and fits within the overall system design. The resulting work product of this process is the final design specification.

This process has the following steps:

- **Sub-System Design**
  Sub-system design is performed by the system experts using the functional requirements, policies and standards, and resource allocations that were developed in the system definition process. If changes to

resource allocations are required, the need is identified here and is then evaluated and approved (or disapproved) during later phases of the iterative design process.

- **Requirements Confirmation**
  Here the design generated in the preceding activity is compared to the functional specification to ensure that it satisfies all of the identified sub-system requirements. The design is also evaluated against policies and standards to ensure that it is compliant with overall system requirements, as well as organizational standards.

- **Integration with Peer Sub-Systems**
  The sub-system design is then evaluated against the design (or functional specification) of its peer sub-systems to ensure that all interfaces are consistent and that it meets installability and interoperability requirements. Resource brokering may occur in this activity, as each sub-system gains a greater understanding of their actual needs.

- **Integration with Accelerator Systems**
  Working with accelerator system experts, the emerging designs are evaluated to ensure that they can be integrated with the beamline and that the accelerator resources (beam quality, characteristics, etc.) that they require can be provided within the proposed design.

- **Integration with Facility**
  During this activity, the configuration and distribution of facilities resources is evaluated to determine if a) the existing resources are adequate, and b) the resources are being distributed to the proper locations. The information gained in this step should be used by the facilities department to identify and prepare for modifications to their infrastructure.

- **Integration with Project Office**
  As discussed earlier, much of the expertise on regulatory and policy compliance exists within the project office. This integration step gives them the opportunity to evaluate the emerging design through the prism of overall project constraints and objectives, and advise the design process as necessary.

- **Documentation & Communication**
  Although listed as a single step, documentation and communication is a continuous activity which is executed throughout the design process to ensure that information about emerging changes is propagated to all sub-system owners as quickly as possible. This information may include a) changes to resource allocations and budgets, b) changes to the functional specification of a sub-system or its defined interfaces, or c) updates to standards and policies that govern the design of all sub-systems.

The Final Design Specification

The iterative design process is repeated until each sub-system's design is sufficiently mature to produce a final design specification. This document has all of the information necessary to fabricate or procure a sub-system capable of meeting its functional requirements and interfacing properly with the larger system.

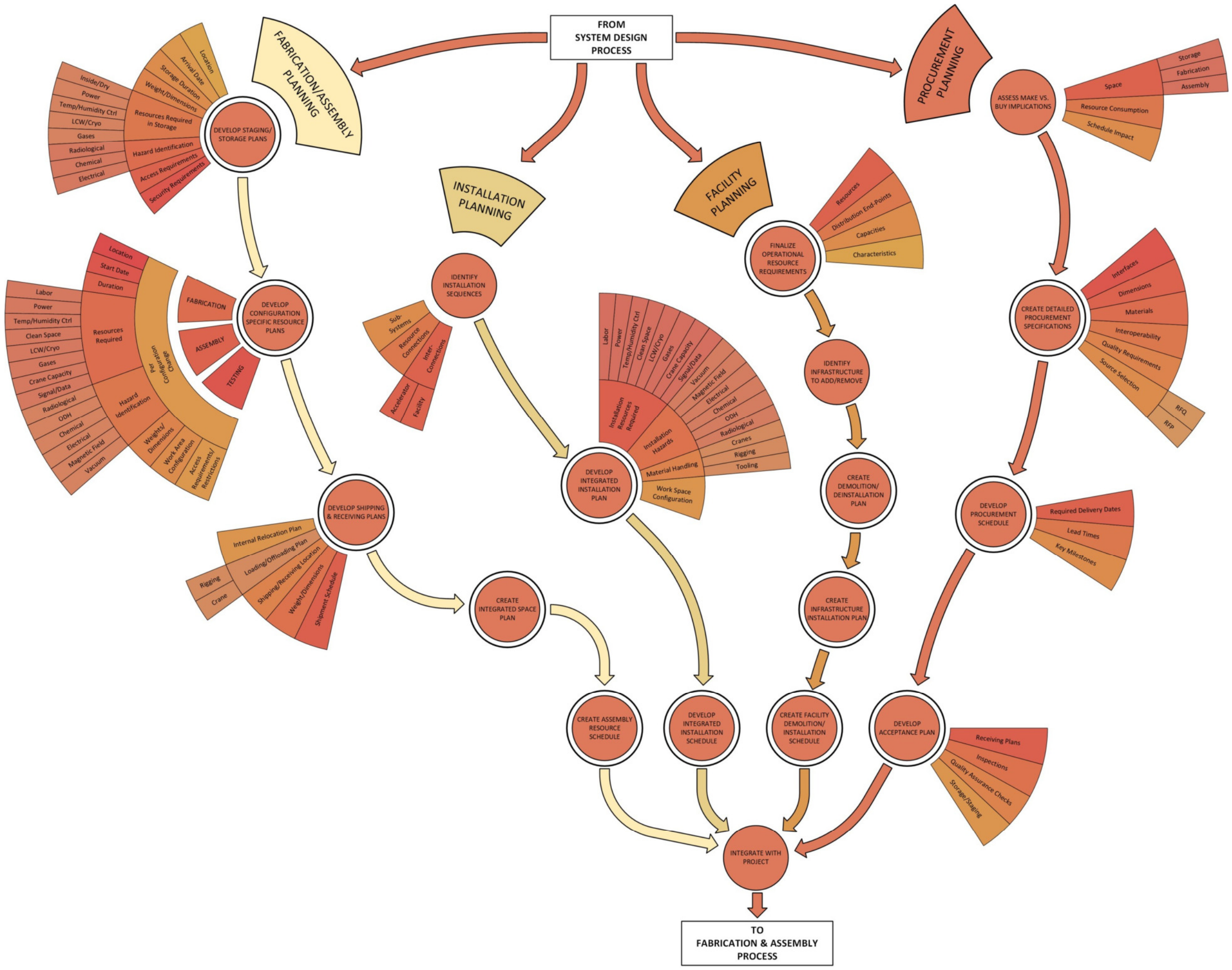

Figure 8. System Integration Planning

INTEGRATION PLANNING

Where the system definition and system design processes examine how the system will be configured in its operating environment, the integration planning process considers the rest of the system acquisition life cycle - from procurement to installation. While this section is the most complicated of the system integration processes, it is also the place where most problems can be identified and eliminated before they impact the project.

The integration planning process is divided into four major activities: fabrication & assembly planning, installation planning, facility planning, and procurement planning. It should be noted that much of the effort in these activities is performed by experts who are not part of the integration process. In order to make this process achievable, only the activities where the system integrator must provide coordination are identified.

Fabrication & Assembly Planning

The fabrication and assembly planning activity addresses every issue that must be resolved to successfully build the detector - from shipping and receiving plans, to construction resources, to staging components after they are assembled. The following sections address the key considerations in each of these areas.

- **Development of Staging/Storage Plans**
  Staging and storage of materials is a continuous effort throughout system integration. Because space is a highly prized, and often constrained resource, space planning must be integrated with the project schedule to determine when materials can arrive, and how quickly they must leave to make room for incoming shipments.

  The following are the key factors that should be considered in storage planning.

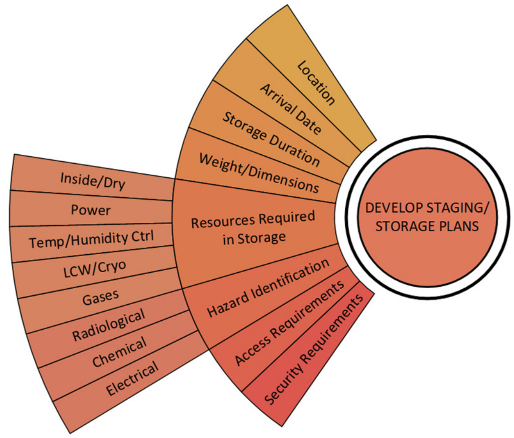

Figure 9. Develop Staging & Storage Plans

Key Factors

- *Location:* where will the components be stored?
- *Arrival Date*: when will the materials arrive?
- *Storage Duration*: how long will they remain at this location before they are moved?
- *Weight/Dimensions*: what are the sizes and weights of the components? Do they require increased floor loading or special material handling equipment? Will they fit through the doors?
- *Resources Required in Storage*: does the material or component require special resources while it is in storage, such as power, temperature and humidity control, gas flows, etc?
- *Hazard Identification*: does the material or component have special hazards associated with it that must be addressed?
- *Access Requirements*: Who will need to access the material while it is in storage, and are there any special security requirements?

- **Development of Configuration Specific Resource Plans**
  During the process of building the sub-systems, there are three activities that are commonly performed: *fabrication, assembly, and testing*. Each of these activities will require different resources and each may require a different workspace configuration.

  Because the sub-detector systems will be sharing space during fabrication and assembly, it is essential that the technical staff plan for changes in their workspace configuration so they can be coordinated with others. The following are key factors that must be considered *for each configuration change.*

Figure 10. Develop Configuration Specific Resource Plans

Key Factors

- *Location*: where will this work be performed?
- *Start Date and Duration*: when does the work begin and how long will it last?

- *Resources Required*: what resources will be required during each stage of the fabrication and assembly process?

  Note that in addition to the traditional facility resources, ***labor*** becomes a consideration at this point in the planning process. What skillsets will be required? Will it be existing staff, contractors or other outside labor?
- *Hazard Identification*: What hazards will be created during the assembly and testing process?
- *Weights/Dimensions*: How will the weights and dimensions of the component evolve during the assembly process? Will floor loading requirements increase when components are combined? Can the fully assembled system be lifted by the existing crane? Can the final product be removed from the building?
- *Work Area Configuration*: How will the work area be laid-out for each activity? How will the resources need to be configured to support the activity?
- *Access Requirements/Restrictions*: What personnel will require access to the area? Are there special training requirements? Will safety or security barriers need to be erected?

- **Development of Shipping and Receiving Plans**
  During the construction of detector systems, components may be moved between several sites before they are finally installed. A sub-system may begin at a university before being shipped to an intermediate facility for testing and, finally, to the operating site for installation. Each movement must be carefully integrated with the overall space plan to ensure success.

  The following are key considerations:

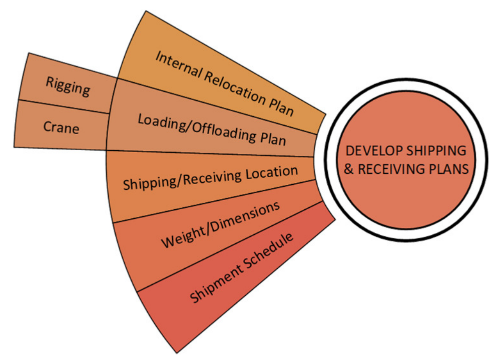

Figure 11. Develop Shipping and Receiving Plans

Key Factors

- *Shipping Logistics*: When and where will the shipment arrive? How large will the packages be and how much will they weigh?
- *Loading/Offloading Plan*: Will special material handing equipment or personnel be required to offload the shipment? Will access restrictions be in place during the offloading process? Will special safety or hazard mitigations be required?
- *Internal Relocation Plan*: How will the shipment be moved from the delivery location to where it will be stored or staged? Has adequate space been allocated and is there a clear pathway for access?

- **Create the Integrated Space Plan**
  The integrated space plan is one of the most significant documents in the system integration process. This document tracks all sub-systems and components and details every time they are relocated or their work space configuration changes. This document is used to determine how space will be allocated and shared, and how resources will be provisioned during each phase of fabrication, assembly, testing, staging and installation.

  The document is populated with information that is collected via the staging plans, configuration specific space plans, and the shipping and receiving plans. It will continue to be updated and referenced throughout the system installation process. Figure 12 shows a composite drawing from an integrated space plan that shows a collection of installed systems. Figure 13 shows a sub-system detail page containing specific information about an individual sub-system and its resource requirements.

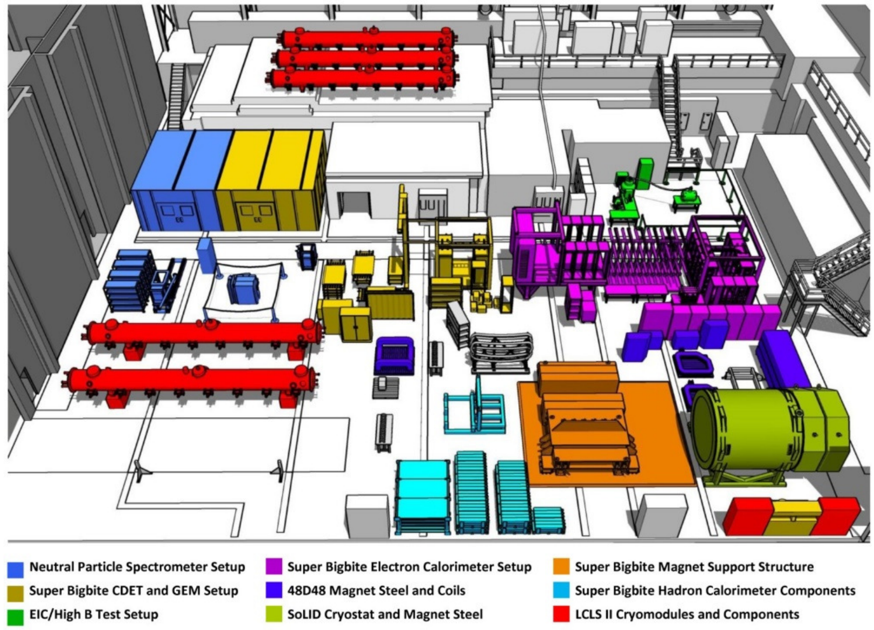

Figure 12. Composite storage/staging map from the integrated space plan.

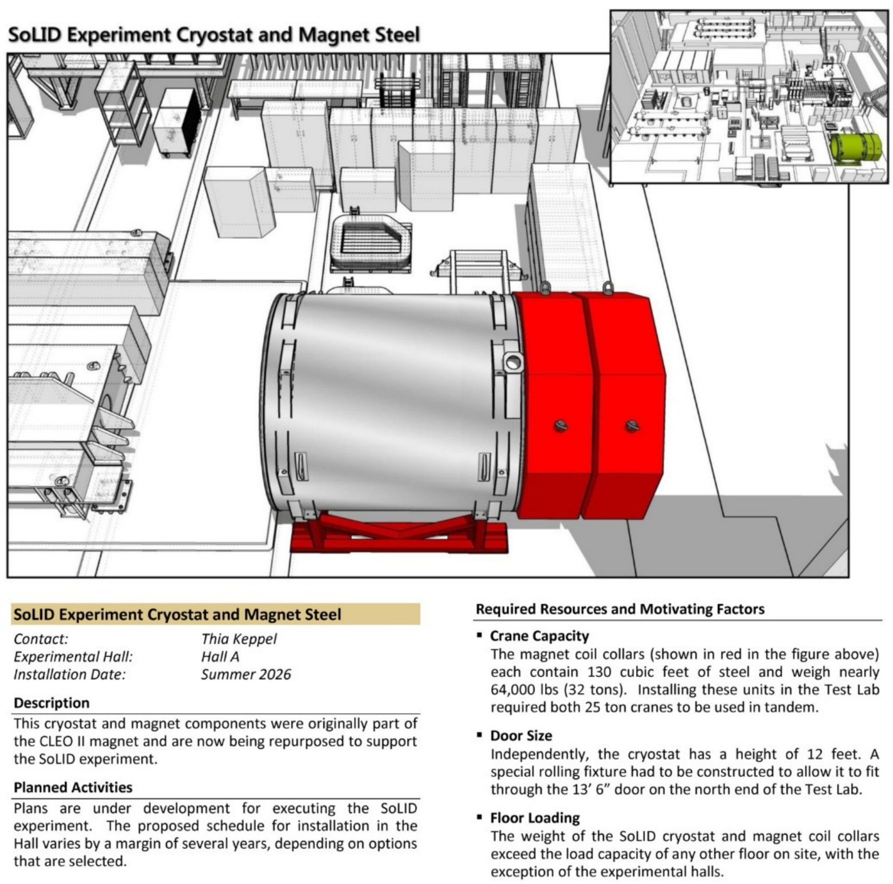

Figure 13. Sub-system specific staging summary from the integrated space plan.

- **Create the Assembly Resource Schedule**
  The assembly resource schedule identifies all of the resources that are available for use, and how and when they will be allocated for assembly, fabrication and testing of the sub-systems. This is an all-inclusive document that must look beyond the specific needs of the project, and consider how resources are shared among all stakeholders within the facility.

  The assembly resource schedule provides the foundation for the integrated resource plan.

Installation Planning

The goal of installation planning is to identify and coordinate all of the resources that will be required to install the detector system and experimental apparatus. Activities must be carefully sequenced to minimize conflicts and to simplify the connection of facilities infrastructure. The following sections identify the major areas that must be considered in the installation planning process.

- **Identify Installation Sequences**

Sub-Systems

The sequence in which sub-systems are installed is largely governed by their placement within the overall system. While planning the installation of each successive sub-system, the integrator must consider accessibility and how interface connections will be made between each sub-system, and between the sub-systems and the facility.

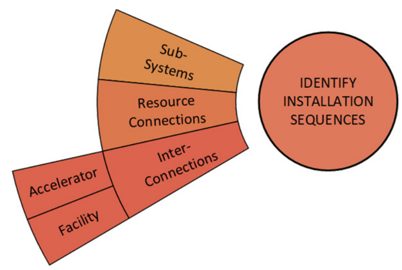

Figure 14. Identify Installation Sequences

Resource Connections

Resource connections for power, LCW and communications cabling must also be sequenced. In addition to developing a plan that makes these connections easy to install, the integrator should also consider system maintenance and organize the connections to facilitate disassembly for service or repair.

Inter-Connecting Systems

Finally, the integrator must consider the sequence in which facilities and accelerator systems will be installed and connected to the experimental apparatus. As part of facilities integration planning, a deinstallation/demolition plan will be developed. The work sequences identified in that document should inform the development of detector installation sequences.

- **Develop the Integrated Installation Plan**
  The integrated installation plan identifies all of the resources that will be used to install the detector sub-systems, as well as installation hazards, material handling requirements and work space configuration.

Installation Resources

This is a comprehensive schedule of all of the resources that will be required to install each sub-system and when they will be needed. This differs from the operational resource list in that these resources are specifically required for system installation and may not be needed for normal operations.

Key among these are the labor resources. The amount of labor, skillsets and labor type *(staff, contract, etc.)* must be identified and coordinated through the project office.

Installation Hazard Analysis

This is a list of specific hazards that will exist during, or be created by, the installation process. The document should identify when the hazard is expected to occur, how long it will last, and what mitigation steps must be taken to prevent injury or damage.

Material Handling Requirements

This section identifies the material handling requirements for each sub-system during the installation process. These include supplemental cranes, rigging, mounting/installation fixtures, and tooling.

Work Space Configuration

The installation process for each sub-system may require customized workspaces within the operating area. These may include special tooling or cleanrooms that are required for preparing components for installation. These work areas and their resource requirements should be defined in detail for inclusion in the integrated space plan.

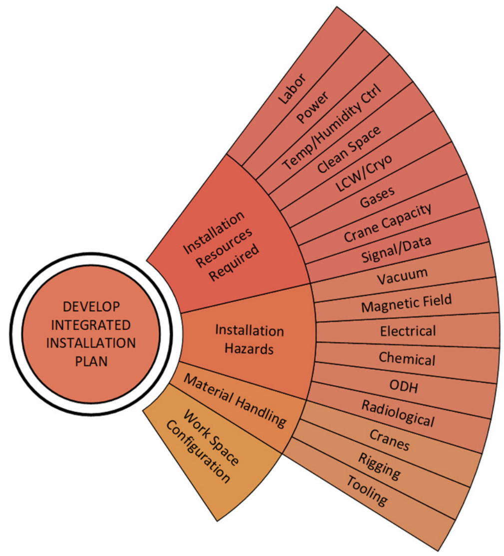

Figure 15. Develop Integrated Installation Plan

- **Develop the Integrated Installation Schedule**
  The final step in the installation planning process is to consolidate all of the information produced in the preceding steps into an integrated installation schedule. This schedule must be coordinated with the project office and the accelerator and facilities schedules to eliminate conflicts and ensure compliance with the overall objectives of the project.

Facility Planning

While facility planning will largely be performed by system experts within the facility department, the system integration team must remain highly involved to ensure that all necessary resources are installed and provisioned. The following are major activities within this process.

- **Finalize Operational Resource Requirements**

Resources

Compare the list of resources that the facilities department will be providing with the specified requirements of the detector sub-systems and other supporting infrastructure. Requirements mismatches and shortfalls should be corrected here, and a final, comprehensive list of required resources should be produced.

Distribution End-Points

Every service that is provide to the detector sub-systems must come from a distribution end-point. These may be LCW taps, network switches or electrical breaker panels. This activity looks

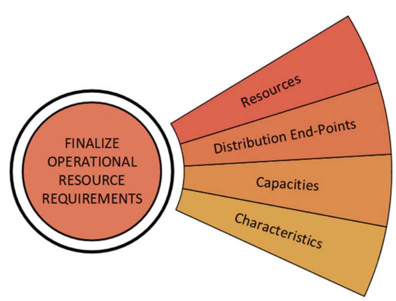

Figure 16. Finalize Operational Resource Requirements

at the inventory of services that are required by the sub-systems and identifies the distribution end-points that must be provided to deliver each resource.

Capacities

Using the list of required resources that was developed earlier, this activity checks to ensure that an adequate amount of each resource has been provisioned to the detector systems. This will include things like the amount of power that has been distributed, gallons of LCW available, or installed tonnage of HVAC.

Characteristics

This activity examines the specific qualities of each resources to ensure that they will meet the needs of the detector sub-systems. For the power systems this might include electrical transformers to produce usable voltages, or the availability of clean and emergency power. For LCW and process cooling, this includes things like required water pressure and flow rate.

- **Identify Infrastructure to Add/Remove**
  Based on the preceding resource evaluation, the facilities department will identify the changes that are required to successfully install and provision services. In many cases, this will require the addition or expansion of distribution systems, however, there may be existing resources that are either, a) no longer needed, or b) interfere with the installation of new equipment. Planners in the facilities department must identify all alterations that will be made to the operating area's infrastructure.

- **Develop Demolition/Deinstallation Plans**
  Demolition and deinstallation requires special consideration as it may impact existing equipment that will be needed for the final configuration. Deinstallation planning should consider if temporary resources will need to be allocated to maintain an existing system during the transition. Further, plans must be made for staging, storing and disposing of waste, as well as components that will be saved for future use. Hazards associated with the removal of components that have been activated by ionizing radiation or that have stored energy must also be considered.

- **Develop Infrastructure Installation Plans**
  Development of infrastructure installation plans is the next step in the facility integration process. This plan identifies services and equipment that must be installed to deliver all resources required by the experimental apparatus, and the supporting facilities and accelerator infrastructure. The configuration of distribution end-points should also be evaluated to confirm that they provide the correct interfaces, capacities and characteristics to satisfy the requirements of the supported systems.

- **Create the Facility Demolition/Installation Schedule**
  With the demolition and installation plans complete, the next step is to determine the timing and sequence of activities that will best meet the demands of the project. In some cases, deinstallation of existing distribution systems may need to be delayed until new systems are installed in order to maintain continuous support. This schedule should identify all of the existing resource dependencies within the system and specify the steps that will be taken to ensure they are satisfied. It should also document how new dependencies will be satisfied in accordance with the overall project schedule.

Procurement Planning

Much of the procurement process is a series of independently regulated activities that might be considered a *'black-box'*. However, there are several key activities within the procurement process where the system integrator must be involved to ensure that resources are available when they are needed. This section will detail several areas of concern that should be monitored to ensure successful integration.

- **Assess Make vs. Buy Implications**
  A key decision in the procurement process is whether a component should be purchased or fabricated. In addition to many other issues that drive that decision, it also raises the following concerns for systems integration.

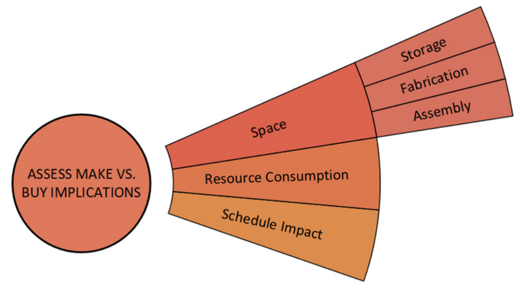

Figure 17. Assess Make vs. Buy Implications

Space Requirements

Building a sub-system or component requires space for fabrication, assembly and testing. This space must be outfitted with the proper infrastructure and must be available, scheduled and allocated.

The space requirements for components that are procured is often less daunting. Procured components will need to be incorporated into the receiving plan and will need to have a staging and storage plan that identifies the duration of time they will be stored and the resources that they need in storage.

Resource Consumption

The infrastructure and physical resources required for constructing components go beyond space and include power, process cooling, specialized tooling and labor. The determination of whether to make or buy a component will be impacted by the existence and availability of necessary resources.

Schedule Impact

As space and other resources are continuously balanced throughout the integration process, the addition of fabrication and assembly activities will need to be carefully coordinated. The scheduled consumption of space, infrastructure and labor must be reviewed to ensure that other sub-systems are not negatively impacted by these activities, and that all work is completed in a timely manner.

- **Create a Detailed Procurement Specifications**
  The procurement specification is developed as a cooperative effort between the procurement department and the system specifiers. In many cases, this document is the only source of information that the supplier will have for what is to be provided and the standards it must satisfy. While it is the role of the system specifiers to ensure that the component meets all of the needs of the sub-system, the system integrator is responsible for ensuring that the procured item will fit within, and interface with, the larger system.

  The following are key factors that the system integrator should be aware of:

Key Factors

- Interfaces and Interconnections

  All interfaces and interconnections that connect the sub-system to its peers (or the facility) should be checked for compatibility. In addition to interface type, the lengths and capacities of these items should also be confirmed.

- Dimensional Specifications

  The procured component must fit within the allocated space and should be designed to be installable in a manner that is consistent with the installation plan.

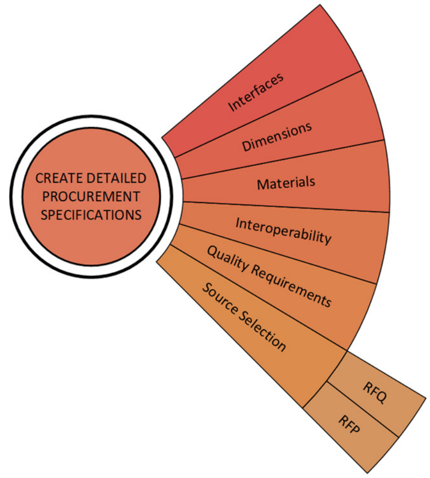

Figure 18. Create a Detailed Procurement Specification

- Materials and Quality Requirements

  While the system designers are fully aware of the material and quality requirements of their own system, there may be additional requirements that are driven by the needs of the peer systems. The system integrator should ensure that all components at the boundary of the sub-system meet the quality standards of the connected peers.

- Interoperability

  The sub-system's features and functionality that are required by its peers should be evaluated and confirmed.

- Source Selection Criteria

  Although source selection largely occurs within the procurement department, the system integrator should ensure that RFQs and RFPs include all pertinent information regarding how the procured item will interface with other sub-systems and the facility.

- **Develop the Procurement Schedule**

  For the system integrator, the procurement schedule is highly coupled to the integrated space plan and to the overall project schedule. Procured items that are received must be stored, and the storage locations must have sufficient resources to maintain them in an acceptable state. Further, the timing and sequence of component deliveries must match the schedule for installing and connecting the sub-system and its peers. The system integrator should work with the project office to determine sufficient lead times for ordering components, and key milestones to ensure that the manufacturer will meet the delivery deadline. Variations from the schedule should be detected early and integrated into the larger schedule.

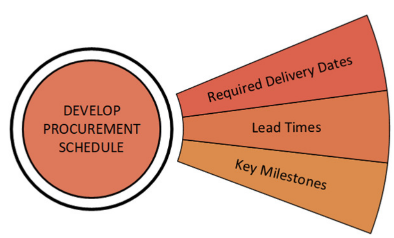

Figure 19. Develop the Procurement Schedule

- **Develop Acceptance Plans**

  The final step in the procurement planning process is the development of an acceptance plan for receiving the procured item. As mentioned earlier, this requires the system integrator to develop a receiving plan that identifies where and when the component will be delivered, how it will be offloaded, and how it will be transported to storage from the receiving location. The storage of the component will need to be included in the integrated space plan, along with the resources that will be required to maintain it.

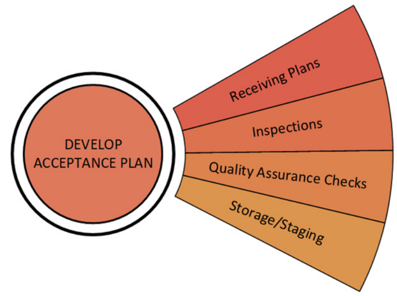

Figure 20. Develop Acceptance Plans

  Upon receiving the component, inspections and quality assurance checks are required to ensure that it meets all specifications. The system integrator should pay special attention to the quality and characteristics of interfaces to ensure that they match what is required by other sub-systems and the facility.

Project Integration

While project integration is shown as the final step in this process, it should be viewed as a continuous activity. Each planning step, from fabrication & assembly to installation, has a discernable impact on the project schedule and should be coordinated and integrated as quickly as possible. Of equal importance, the project office must regularly provide information on changing conditions (priorities, funding profiles, resource availability, etc.) that will impact planning for the detector sub-systems. The need for continuous integration with the project office is essential in all of the logistics planning activities, and only becomes more critical in later stages when assembly and installation are performed.

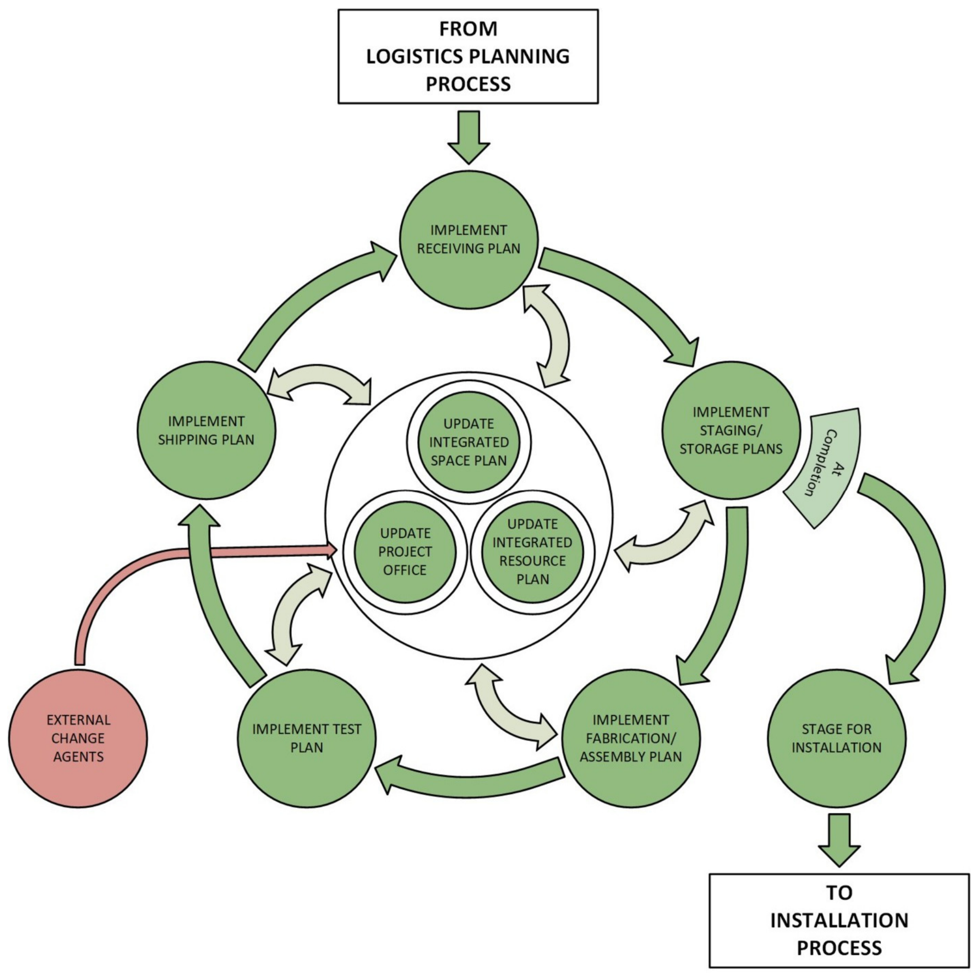

Figure 21. The Fabrication & Assembly Loop

FABRICATION & ASSEMBLY LOOP

If the logistics planning activities were performed well, then both the assembly and installation processes should largely be a matter of executing the plans that were created earlier. To ensure a smooth work flow, it will also be necessary to continuously maintain the integrated space and resource plans, and to monitor for external changes that might impact work. To achieve this, the planning documents and integration with the project office are central to the fabrication & assembly process.

The integrated space and resource plans detail the timing and distribution of resources. As work is completed, the documents must be updated to indicate that resources have been released and are available for other activities. If there are delays, the documents must reflect that as well, so that other sub-system owners who are relying on those resources can take appropriate action.

Changes from outside of the project, particularly those involving budget allocations and regulatory changes, may *(or may not)* have a significant impact on activities. Because of this, external changes should be filtered through the project office so that only consequential issues are brought to the system integration team.

Because most of the fabrication & assembly activities must be iterated several times for a sub-system, the process is represented as a loop. As an example, a component may be procured, received, assembled and tested at one facility, before being shipped to another facility where it is added to a larger assembly and then tested and shipped again. Multiple movements between work and storage areas within a single facility are also common. Therefore, the system integrator should view each activity with an eye to what activity will happen next, and ensure that needed resources are both available and scheduled.

The following are the major activities of the fabrication & assembly loop:

Implement Receiving Plans

This is the process by which procured materials, sub-assemblies and components are received at the facility. Using the plans developed earlier, the shipments must be safely offloaded at a designated area, inspected for quality, and then transported to a long-term staging or storage location.

Implement Staging & Storage Plans

Staging and storage activities manage the flow of materials through the facility as they are fabricated, assembled and finally installed. The integrated space plan must be continuously updated as space is allocated and released. This, of course, is not limited to the space being used for the project; other outside activities that consume space must also be monitored.

As discussed earlier, staging and storage of sub-systems and components may also have special resource requirements. The integrated resource plan must also be maintained as resources are consumed.

Implement Fabrication & Assembly Plans

The fabrication and assembly of components also consumes space and resources. During this activity, the systems integrator must ensure that resource consumption remains consistent with what has been allocated, and that any variations are integrated with the space and resource plans, as well as the project office.

Implement Test Plans

In many cases, testing will be conducted in the same location as fabrication and assembly; however, the space and resource requirements may differ significantly. As workspace configurations change, the system integrator must ensure that allocated resources are released and that materials or debris from the assembly process do not continue to consume space.

Implement Shipping Plan

Upon completion, many components will be shipped to another location for either continued assembly, storage or installation. The shipping plans developed in the logistics planning process are executed here, and the loop continues with the execution of a receiving plan on the other end.

Stage for Installation

Once all assembly and testing has been completed, the loop terminates as the completed sub-system is staged for installation. Again, staging of components requires space and other resources, and the integrated space and resource plans must be updated accordingly.

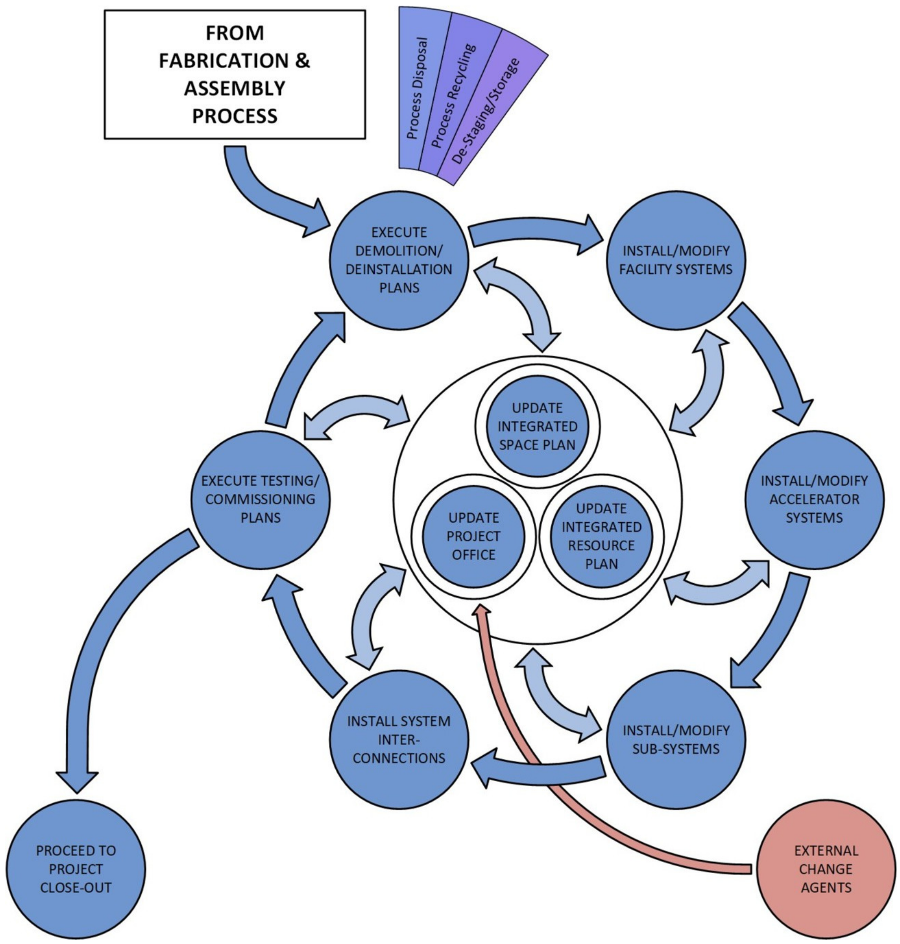

Figure 22. System Installation Loop

SYSTEM INSTALLATION LOOP

The final step in the detector systems integration process is the installation of sub-systems. As with the fabrication and assembly loop, this is an iterative process that centers around the integration and planning documents. As before, all external changes are integrated through the project office and the space and resource plans are monitored and maintained as activities are conducted.

The following are the major activities within this process.

Execute Demolition/Deinstallation Plans

Before new systems can be installed, any existing, unneeded infrastructure must be removed. Many of these activities will have been planned and scheduled during the logistics planning process. The system integrator should monitor the activities to ensure that they are conducted in the correct sequence, and to be prepared in the event that unexpected dependencies are found.

Install/Modify Facility and Accelerator Systems

In most cases, facility and accelerator systems will need to be installed and connected before detector sub-systems can be installed. These activities largely rely on following the plans that were developed earlier and monitoring for changes. For the systems integrator, managing the movement of transient materials and tooling through the operating area will be critical. Equipment, tools, packaging and debris should be removed from the area as quickly as possible. Anything that is stored for future use should be reflected in the integrated space plan.

Install/Modify Detector Sub-Systems

The installation of sub-detectors is the next step in this sequence. Technicians and system designers with specific expertise in their equipment are responsible for the installation process. The role of the system integrator is to ensure that they do not overconsume space or other resources during the installation. Any variations in the installation process must be communicated to the other sub-system owners and to the project office.

Install System Interconnections

System interconnections are the interfaces between the various sub-systems, the facility and the accelerator. These largely occur at boundaries between sub-systems, which makes them especially prone to miscommunication and confusion. During the system design process, the interfaces between sub-systems should have been clearly defined, and later confirmed during the procurement and acquisition activities. As before, the role of the system integrator is to detect any deviations from the plan and communicate them to all stakeholders.

Execute Testing and Commissioning Plans

Performing testing and commissioning often requires resources that are not part of normal operations. A detailed list of these resources should have been identified during the logistics planning process. The system integrator should ensure that these resources are distributed in accordance with the project plan, that they are released when they are no longer needed, and that the integrated resource plan is upgraded to reflect changes as they occur.

Proceed to Project Close-Out

In the final step of the detector integration process, project closeout is performed and the integration documents are finalized. This process involves identifying all parts, sub-components, tooling or spares that are still in storage and determining if they will be kept or disposed of. Space that was allocated to the sub-systems is released, as are any resources that have been retained. Upon completion, all planning documents are handed off to the project office for archiving, or to be integrated into future operational plans.

CONCLUSION

As this document makes clear, the detector integration process has many distinct steps and relies on documentation and communications between sub-systems being meticulously maintained. Although this model struggles to minimize activities and keep the process as simple as possible, the sheer volume of data points that the system integrator will need to monitor is likely to require automated solutions. In future work, the detector systems integration model will likely be coupled with templates, forms, spreadsheets and databases that can be adapted for each project.

As this is the first version of the model, additions and alterations will no doubt follow. Still, when building on this model, one should exercise thrift at every step. No activity should be added that does not require integration between sub-systems or the facility; no document should be added that does not directly contribute to the integration process; and any activities that require regulatory or policy expertise, should be abstracted from the integration process as much as possible. Exercising discipline in maintaining the integration model is the best way to keep the process of system integration highly focused. This will help to ensure system interoperability, and will greatly increase the likelihood of success.

GENERAL DETECTOR SYSTEMS INTEGRATION

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