Facility Construction Plan

GDD-07-45

GENI: Global Environment for Network Innovations

April 22, 2007

Status: Draft (Version 0.6)

Note to the reader: this document is a work in progress and continues to evolve rapidly. Certain aspects of the GENI architecture are not yet addressed at all, and, for those aspects that are addressed here, a number of unresolved issues are identified in the text. Further, due to the active development and editing process, some portions of the document may be logically inconsistent with others.

This document is prepared by the GENI Planning Group:

Larry Peterson, Princeton

Tom Anderson, Washington

Dan Blumenthal, UCSB

Dean Casey, Ngenet Research

David Clark, MIT

Deborah Estrin, UCLA

Joe Evans, Kansas

Nick McKeown, Stanford

Dipankar Raychaudhuri, Rutgers

Mike Reiter, CMU

Jennifer Rexford, Princeton

Scott Shenker, Berkeley

Amin Vahdat, UCSD

John Wroclawski, USC/ISI

Document Authors:

Terry Benzel, John Wroclawski, Dean Casey

This work is supported in part by NSF grants CNS-0540815 and CNS-0631422.

Revision History:

Version	Changes log	Date
v.0.1	Original outline	January 29, 2007
v.0.2	Initial PM material	
v.0.3	Approach and process material	March 18, 2007
v.0.4	Internal edits	Unreleased
v.0.5	Internal edits	Unreleased
v.0.6	Revisions to intro, process material. Risk and Change mgmt revised and moved to appendix	April 24, 2007

Table of Contents

1 Introduction

This document lays out the plan for building the GENI facility, and describes the management processes and offices that will govern and direct the effort.

This document has been prepared for GENI's Conceptual Design Review. Its primary purpose is to present the construction plan, together with supporting management processes and functions, at the conceptual level. In addition, it discusses a small number of pre-construction activities that are important to the further refinement of the construction plan.

2 Factors Influencing the Construction Plan

GENI's construction plan is directly influenced by a number of factors, including both factors common to all large projects and factors unique to GENI. In this section we outline attributes of the GENI project that directly influence our choice of approach and mechanism for its construction.

2.1 The GENI Construction Task

Successful completion of the GENI facility will require that a number of different *types* of construction tasks be completed and integrated. We describe each of these task types briefly.

Facility Construction. A significant portion of the overall GENI construction effort lies in facility construction – fiber plant, computing cluster machine rooms, and the like. This construction element is relatively conventional in nature. It will be dominated by traditional facility construction concerns of planning, scheduling, maximizing return on financial investment, and management of risk through vendor selection, qualification, etc.

Custom Hardware Construction. A fraction of the overall GENI construction effort is dedicated to the development of specialized computing and communication equipment – programmable routers, wireless nodes, and the like. This element may be viewed primarily as an advanced development task, with some aspects of facility construction included. Risk management for this element spans the full range from design risk to vendor qualification and execution risk.

Software Development. A major fraction of the overall GENI construction effort will be devoted to software development. It is this element that primarily differentiates GENI construction from a traditional "bricks and mortar" construction project, or even the construction of a traditional scientific instrument. The major forces creating this differentiation are the flexibility and malleability of software together with the expectations of GENI's user community, for which the research process heavily depends on this malleability. The impact of these forces and research processes on the GENI construction plan is discussed further below.

Operational Validation During the Construction Period. Because GENI is a composite facility, with an incremental construction plan, it is possible for portions of the GENI facility to become operational, and be incorporated into the research process, before the full facility is complete. The GENI construction plan benefits from this capability by allowing the constructors of GENI and the research community to obtain early, realistic, validation of key GENI system elements and functions, and by allowing the community to provide feedback to GENI's constructors during the construction period, ensuring that the final facility is as close to meeting the needs of its research community as possible.

The construction plan presented here is heavily shaped by two factors described above, GENI's software-intensive nature and the potential for incremental operational validation and feedback during the construction process. Additionally, it is shaped by the planning group's recognition that the full GENI universe, as imagined, will not be limited to NSF-sponsored MREFC construction, but will grow to include federation with other national and international testbeds, industrially contributed resources, and other contributions from interested players.

2.2 Nature of the GENI Project

Although much of GENI construction will be concerned with the traditional facility construction elements of schedule, budget, return on investment, and managing risk, GENI's construction plan is fundamentally shaped by a single, somewhat nontraditional, requirement. That requirement is that GENI - particularly in terms of its software development activities - be constructed in an extensible, open manner, based on a system architecture and facility design that encourages and supports this extensibility. At the same time, technical robustness as well as management, budget, and scheduling accountability, must be preserved.

It is important to acknowledge that the requirement for open extensibility alters the nature of, and may add significant overhead to, GENI's construction process, compared to the hypothetical alternative of managing GENI's construction as a fixed, closed, fully specified system constructed in a monolithic fashion.

For this reason we briefly review reasons that extensibility is central to meeting the GENI project's goals. There are three:

- GENI must be continually responsive to changing technical drivers and research requirements. It is impossible to design and implement a facility today that can meet the needs of GENI's customer communities for the next 15 years. Instead, it is necessary to design a facility that can meet the needs of the customer communities today, and provides a *structure* for continuing to meet those needs going forward through a process of refresh and extension.

- GENI cannot fully meet its design objectives if implemented as a closed project. While NSF funding will provide the core facility infrastructure and design, the GENI system designers believe that GENI will of necessity only reach its full capabilities by leveraging additional infrastructure made available by non-NSF sources.

- GENI must be extensible and open to achieve its technology transfer goal. A core objective of the project is lowering the barrier to transition and widespread adoption of new networking capabilities and technologies. In other words, and perhaps unlike some other MREFC projects, GENI will not be fully successful if the primary result of its construction is an increased level of academic publication. For this reason, it is *essential* that GENI's design and construction plans facilitate the easy transfer of new concepts and ideas *into* GENI, as well as the transfer of validated and proven research results *out* of GENI.

Beyond meeting this basic extensibility requirement several aspects of GENI's design directly influence our approach to construction. These aspects create both challenges and opportunities during the construction period. Among the most important are that:

GENI is *complex.* In common with many large projects, GENI's complexity is high. The construction and construction management processes employed for GENI must be capable of tracking and managing this complexity.

GENI is *heterogeneous.* The project includes a diverse set of networking and distributed system technologies, a rich collection of software services, and spans a wide geographic area. A significant number of different skillsets, expertises, and perhaps cultural perspectives, must be brought together to successfully construct the project.

GENI can be *incrementally useful.* Unlike many traditional large-scale systems projects, GENI is not an all or nothing proposition. Rather, individual subsystems of GENI may be useful as soon as they are completed, and early integration of developing subsystems will provide function useful to GENI's user communities even before the individual subsystems have reached their full capabilities.

GENI is *intrinsically malleable*. Unlike many large, complex projects, GENI is inherently modifiable; from a technical perspective it is easy to extend, change, and retarget its function. This inherent malleability is both an opportunity, in that it makes it easy to augment the system or correct mistakes, and a risk, in that this perceived freedom creates great challenges to schedule, budget, and project convergence.

Additionally, certain key properties of GENI's user community influence our construction plan. Among these the most important are:

GENI's user community is *closely coupled to its builder community*. In contrast with the great majority of large systems projects, a significant segment of GENI's intended user community is, and perceives itself to be, skilled in the design and building of facilities similar to GENI. This factor offers a significant opportunity to ensure that GENIs design and construction meets the needs of its user community, but also creates important risks, as outlined in Section 2.3 .

GENI's user community is prepared to *contribute to the design and evolution* of GENI. Understanding that GENI is incrementally useful and inherently malleable, large portions of GENI's intended researcher user community are prepared, and expect, to contribute to the development of GENI, and to assist it in evolving as research needs advance.

2.3 Nature of risks to GENI's success

Our plan for the construction of GENI is heavily influenced by the need to manage and mitigate the risks facing the project. Due to the attributes described above, the GENI program is characterized by three broad classes of risk: technical, process, and community. We briefly discuss each of these risk categories, together with their relationship to the GENI project.

Technical risk in GENI derives primarily from the complex software-intensive design, the expectation that key components of the system will be at or beyond the current state of the art in technical sophistication, and the requirement that the overall system architecture provide sufficient modularity, deployment timing independence, and isolation that individual portions of the system can be developed and deployed relatively independently.

GENI's *process risk* is relatively broad in nature. Examples of process risk in GENI might include such factors as insufficient availability of developer resources (skilled research programmers and engineers) to build the project; a software development strategy that fails to deliver reliable, deployable software in GENI's complex environment; failure of the GENI designers to deliver a workable or appropriately scoped design; or a contracting model that fails to build and support the necessary prototyping and construction teams and capabilities.

GENI's *community risk*s include such factors as the GENI project failing to meet the needs of its user community; the possibility that the project is not perceived as fair and open to community input in the setting of the facility's goals, capabilities, or design; the possibility that the project is perceived as not likely to succeed, causing skepticism to grow and community support to be lost; and that the project fails to communicate involvement opportunities to the community effectively, or fails to facilitate community involvement in the design, engineering, contracting, and construction process.

Beyond understanding each class of risk, it is critical to recognize the existence of *tradeoffs* between mitigation efforts across the three risk classes. Recognizing and accommodating the existence of this tradeoff is fundamental to managing risk in GENI. Actions which rationally mitigate technical or process risk could easily *increase* community risk beyond acceptable limits – perhaps by disenfranchising a class of potential GENI developer or failing to accommodate a newly developed technology the research community customer perceives as critical. Similarly, actions that minimize community risk could simultaneously lead to greatly increased cost, schedule, or technical risk. A core capability of the IMaGENI risk mitigation plan is its ability to make these tradeoffs effectively.

A second major aspect of GENI's risk profile is that many of the risks inherent in the GENI effort are also critical sources of opportunity. A clear example of a risk that can be managed into an opportunity is unexpected advancement in technical state of the art somewhere in the builder/developer community. GENI's aggressive science goals and dependence on advanced technical capabilities essentially require that significant risks be taken, and thus managed and mitigated, if the project is to meet the full range of its objectives. Because the very risks that make GENI most challenging also create the greatest opportunities for it to succeed, our construction plan focuses on managing, rather than completely eliminating, risk and converting risk to opportunity.

3 Construction Plan

This and the following section describe, in concept, our construction plan for GENI. In this section, we outline the overall approach to construction and describe key processes and elements in further detail. In Section 4 , we outline key management functions and processes.

We recognize that successful construction depends on the adoption of both sound engineering practices and sound management processes. This document outlines our approach to both, leveraging ideas put forward in supportive design documents [GDD-06-38, GDD-06-34].

3.1 Approach

We summarize our approach to building GENI as follows:

- **Deploy early and build incrementally.** It is a well known result of computer science research that in software or hardware construction efforts, errors are cheapest to fix when they are caught early. The best way to do that is to put the system into active use at the earliest possible moment, gain live experience with the system, and incrementally evolve the system based on what you learn. This also implies that at each stage of construction, the facility is in a state that is can be used by at least a subset of the research community.
- **Integrate development and deployment.** GENI is a large and widely distributed facility. It should employ a scalable integration strategy that leverages the decentralized nature of the project, as opposed to depend on a centralized integration team. To the extent possible, development teams should be involved in integration and testing, and in some cases, even deployment. Centralization is largely limited to "commissioning" tasks that validate that the delivered system meets the specification, and assigns responsibility for any failures that do occur.
- **Provide opportunity and structure for outside contributions.** GENI will not be limited to technologies and subsystems built under contract for this project. Our approach fosters an environment in which anyone wishing to contribute useful technology has a means to do so, and conversely, that the construction plan allows for the possibility that unplanned technology will become available for inclusion in the facility.

While this plan is specific to GENI, our overall approach is congruent with the "open source" system development model that has been widely successful in the academic and research communities and is rapidly gaining currency in the commercial and government arenas. Raymond [ref] describes the Open Source Development (OSD) model as deriving from two fundamental principles:

- **OSD Principle 1:** Release early, release often, and listen to your users.
  - This principle, in common with other "agile" software development strategies, recognizes that a tight and responsive feedback look between the developer and the user (customer) greatly improves the effectiveness of the project construction process. The OSD model implements this principle with mechanisms and management strategies that include frequent releases of incrementally improved systems, subsystems, and components, together with well defined and visible processes for evaluating the results and collecting user feedback.
- **OSD Principle 2:** Treat your users as co-developers.
  - This principle recognizes that in the OSD model many users are potential system development contributors as well. The OSD model implements this principle with mechanisms of two types: *management mechanisms* that foster a broad base of potential developers, transparent processes, and low barriers to entry as a contributor, and *technical mechanisms* that include strategically and carefully defined system interfaces, functional documentation, and code/data repositories and change control mechanisms

that encourage parallel, potentially competing threads of development, and ease entry into the process.

The plan presented here applies this model to the specific context and constraints of the GENI project and the MREFC account. We identify the following GENI-specific issues and requirements, which the construction plan is intended to address:

- GENI will be developed by a diverse community distributed across the country. Various groups will own the development and maintenance of pieces of the infrastructure. This development model attempts to leverage the expertise of multiple communities of expertise to ensure best-of-class components, but these different communities typically make use of substantially different development processes and standards. Further, distributed development complicates integration of the components into a coherent package.

- There is a complex set of dependencies between components. As an example, the GENI storage service depends on the security and identity services, and the global slice embedding service depends on interface consistency across wireless, optical and wired components. Dependencies introduce complexities at many levels including testing (versions must match), development serialization (dependent components must be available to complete development), and debugging (root cause analysis).

- GENI will incorporate hardware and software that is not developed or maintained by the GENI community. These "off-the-shelf" components will change over time and the changes will be independent of GENI's schedule. Examples include security patches for an operating system or service, new releases of hardware, or applications with new features. Ongoing maintenance of GENI components must accommodate these changes.

- The technology developed for GENI is likely to be adopted and extended by other communities that are not controlled by GENI. We expect that parallel efforts in Asia and Europe will adopt portions of GENI. In order to mainline GENI technology and results, we expect industry to productize portions of the technology. Finally, we expect that various research communities that are users of GENI will extend the functionality of GENI to support new kinds of experimentation.

- The facility itself will be distributed. This impacts the construction process by substantially increasing both coordination costs and the cost to find and fix defects in the field.

- Taken together, these matters imply that the plan must meet two explicit sub-objectives: it must understand and leverage the capabilities of GENI's user community, and it must incorporate monitoring, steering, and decision-making processes and tools that bring sufficient coordination, oversight and management to a highly decentralized construction activity.

- We note that this conceptual construction plan is focused primarily on successful completion of GENI's highest-risk elements; the software services and systems that it incorporates. This attention is due to two factors. The first is the intrinsic, and dominant, complexity and risk associated with this portion of the project, as recognized by both the GENI planning group and many previous reviewers of the effort. The second is concern among planning group and project management team members about the significant potential mismatch between GENI's nature and requirements and the "waterfall" construction planning and management process historically[1] employed in many government-sponsored systems efforts.

- While the construction plan described here is focused on the software task, two other aspects of the project are considered as well. The first is that portion of the project construction budget devoted to development of unique or customized hardware components. Increasingly, experience suggests that such efforts can be managed using the same OSD principles and approaches, if not exactly the same tools, as software development projects, and we do so in this plan. The second additional aspect of the GENI that must be considered is the substantial task of facilities acquisition and deployment – the purchase and installation of off the shelf hardware, lease or purchase of fiber plant, and similar tasks. At the conceptual level of this construction plan we note that standard models for performing these tasks – vendor qualification, contracting, legal, risk management, etc. – are well established and well understood, and we anticipate that GENI will employ these well-proven models, executed by a competent contracting team. We do not perceive these activities as generating the dominant risks within the GENI construction process.

3.2 Actors and Roles

This section describes the primary actors within the GENI construction plan. Note that our intent in this version of the plan is to describe roles rather than detailed organizational positioning or administrative requirements. A future version of the plan should be expected to make these matters concrete.

3.2.1 Construction Teams

The technical work of constructing GENI will be carried out by approximately 20 design and construction teams. Teams are sized appropriately to the particular area of responsibility, and drawn from communities with expertise in their particular construction task. Each team is managed by a team leader, and operates under the auspices of a contract to the GENI Project Office. Two issues are of particular note:

- In many cases, teams will be responsible for the continuing design and evolution of their portion of the GENI facility, as well as its construction.

- To meet the goals of GENI, teams will be drawn from a wide range of backgrounds and organizational histories, ranging from traditional facilities installation and maintenance contractors to research and advanced development organizations. For this, reason, teams will exhibit a wide range of cultural perspectives and levels of familiarity with formal large-scale systems construction and construction management processes.

---

[1] Although increasingly less so at present.

3.2.2 Technical Design Coordination Group

While individual Construction Teams are responsible for the development of specific GENI components and subsystems, technical direction for the project as a whole will come from a Technical Design Coordination Group, which includes key staff from the GENI Project Office, representatives of the Construction Teams, representatives of the GENI Science Council, and additional individuals chosen for their expertise.

The TDCG will serve much the same role during the construction process as today's GENI Planning Group and Working Groups have served in the initial planning process. Recognizing the requirement for an incremental construction model, the TDCG will be responsible for defining the evolution and technical roadmap for the GENI facility, taking into account the requirements of the research community, the latest available technologies, and the realities of the construction process (e.g. budgets, engineering challenges, schedules, etc.). It will leverage the GENI community's technical expertise, balance science requirements with engineering and costing realities, and produce both a target design and a feasible roadmap to realize that design. This is not a one-time effort. We expect the underlying technologies will change rapidly and the requirements the community places on GENI will continue to mature, meaning that the TDCG must continually adapt and evolve GENI's design throughout the lifetime of the project.

The key to success for the TDCG is to develop a deep grasp of all of the factors that influence the facility—science requirements, available technologies, engineering constraints, budgeting and scheduling realities—and to balance and prioritize these factors to produce a coherent design. Success will depend on active participation from the technical community. We expect the TDCG will start with the 60+ people that have contributed to planning efforts up to this point, but then grow to include experts in areas not currently represented, as well as sub-contractors that will eventually be selected to construct various pieces of GENI. It is important to recognize that while we expect there to be overlap between TDCG participants and the GENI Science Council, the TDCG is primarily focused on the "community of builders" of GENI, while the GSC primarily represents GENI's "community of users."

3.2.3 Systems Engineering Group

The Systems Engineering Group collaborates with and augments the Technical Design Coordinating Group, providing engineering expertise needed to transform high-level designs into detailed specifications. The SEG is structured as a supportive, developer-friendly office that will a) establish engineering guidelines and procedures necessary to ensure a coherent and robust facility, b) select, establish, and maintain the necessary tools and support technologies to coordinate development and construction activities, and c) provide the infrastructure necessary to collect and manage design requirements and specification artifacts from the developer and vendor communities via the TDCG.

We note that this characterization of the Systems Engineering function differs somewhat from the "classical" aerospace/DoD model of a systems engineering office. The distinction is intentional. In our model, many of the roles of the classical Systems Engineering Office, such as requirements generation and allocation, are carried out primarily within the TDCG, with the collaboration and advice of the SEG – in some sense the two entities together comprise a classical SEO. The reason for this, and a primary distinction between the TDCG and the SEG, is that our use of the open development model implies that many processes are decentralized to the extent possible (the TDCG) while coherence and management control require that some processes and decisions be centralized (the SEG). Our concept of integrating TDCG/SEG activity is described further in Section XX.

3.2.4 Project Management and Business Processes Group

The project management group (PMG) is responsible for establishing and providing project management (change management, risk management and mitigation, etc) processes for the period of GENI construction. These matters are discussed further in Section **Error! Reference source not found.**. A key aspect of the project management process employed is that it provides transparency and information flow across the Construction Teams and the TDCG.**Error! Reference source not found.**

Additionally, the Project Management Group is responsible for business processes that directly impact the model of facility construction implemented by this plan. Of prime importance is the contracting model we employ, which is designed explicitly to address the requirements outlined Section 3.1 .

3.3 Procedures

The focus of this discussion is the definition of a *plan* for managing the construction of the GENI facility. The plan should cover the approach, procedures, organization and tools required to construct the facility while managing risk and engaging the community. Prior to the construction phase there are still many activities required to capture the existing design artefacts, supporting refinement of the research planning, managing the solicitation, evaluation and award of prototyping subcontracts, creating detailed construction and project execution plans, documenting progress and presenting incremental plans at the reviews associated with each MREFC stage. Thus, the Construction Plan defines a framework that will continue to grow and be influenced by the remaining stages from planning to construction.

3.3.1 Functional Milestones

GENI construction employs the concept of *functional milestones* to provide cross-team coherence in the construction process, create the structure for frequent checkpoints and feedback from the community, and provide the framework for EVM-based evaluation of construction progress.

Concept of functional milestones, releases. What makes a good milestone?

Multi-dimensional, important criteria, property of visible integrated, cost units checkpoints schedule

3.3.2 Staging and Milestone Selection

Talk about – transforming WBS dependency graph to staging structure . this is a pre construction activity around resource allocation. The WBS dependency graph gives only the path constraints – the task here is to a) incorporate resource constraints, and then b) to create intermediate scheduling points around functional milestones, if necessary by reallocating resources appropriately.

3.3.3 Team selection

The fundamental mechanism underlying the process for contractor selection is the risk mitigation and opportunity optimization strategy presented above. This framework guides prioritized decisions about what work should be carried out during construction.

Timely procurement and deployment of emerging, cutting edge science and technologies is critical to support the GENI goal of ensuring that the next stage of Internet transformation will be guided by the best possible network science, experimentation, design and engineering. However, efficient and timely procurement processes must be complemented by available pool of technology suppliers and appropriate project management controls. Contracting activities of the GPO under the environment of the NSF and computing community goals can represent significant risks to the MREFC phase of GENI. Definition of a technology procurement process must address these challenges in innovative ways within the established frameworks of NSF's Cooperative Agreements and Grants.

The recommended subcontracting strategy is explicitly crafted to serve as a risk reduction mechanism. It is unique in its ability to draw on the capabilities of both academia and industry in order to:

- to provide powerful incentives for GPO success while also promising stability of funding and staff to universities
- to simultaneously create flexibility and foster on-time/on-budget deliverables and
- to encourage and facilitate participation by a broad range of organizations, including those historically underrepresented in the systems building communities.

As a consequence of this strategy, the resulting teams involving shared responsibilities between Universities, other non-traditional contracting organizations and industry players represent a win-win situation to team mates as well as NSF, MREFC and GENI. Cutting edge ideas can get into industrial products much quicker while weaker players become more capable for the future through mentoring.

3.3.4 Contracting

Complementing the use of functional milestones to implement an incremental construction and rollout strategy, we adopt a multi-tier "leader-follower" contracting strategy for Construction Teams. This model has been proven in DoD contracting to both mitigate risk (multiple contractors working on high risk items) and to freeze cost and schedule on close in milestones while allowing requirements and specifications to mature on farther out milestones.

A primary benefit of this approach is that it directly addresses the requirements that the design of the GENI facility have some fluidity (thus enabling the cutting edge of innovation to be incorporated), while still meeting strict cost and schedule requirements.

As described in Section 3 of this document, the technical design and deployment process for GENI is planned around an incremental "build and deploy" series of milestones. From these the project management function (in consultation with the GSC, and following the procedure of

Section 3.3.2) will identify a series of 10-15 functional milestones, that define visible functional capability of GENI upon completion of each milestone.

On average 3-4 milestones will be *active* at any given time. Active means that specific, narrowly defined task activities necessary to complete the functional milestone are underway. When a functional milestone is in the active state, technical requirements, architecture, and design decisions appropriate to the completion of that milestone as well as the cost and schedule will be set and unchangeable. Further, all contracts and task orders necessary to implement the milestone will be in place.

For *inactive* functional milestones, only cost limits and schedule targets will be set, thus allowing architecture and design innovation to be free within the limits to go wherever the design community wishes to go. It is anticipated that a close coordination will exist between the technical design function and the procurement process to assure that what is procured and therefore a part of the GENI evolution is the best snap shot of what the community envisions when each functional milestone transitions to the active state.

Leader-Follower Contracting- The second key feature of this plan's contracting model is the use of multi-tiered contracting. This provides flexibility through the following four types of subcontracts.

- Type 1 - Preferred Source (for Critical Hardware and Software Elements)
- Type 2 - Competing Source (for Critical Hardware and Software Elements)
- Type 3 – Development Source (for Hardware and Software Upgrades and GENI Architectural Changes)
- Type 4 – Special Circumstances Contracts

For Type 1 and Type 2 subcontracts (a variant of contracting sometimes called leader/follower), multiple bidders will be selected from a *pre-qualified bidders list* (sometimes referred to as an IDIQ contract) to bid on the task, with the Type 1 "preferred source" contract award going to the potentially strongest bidder. One or two additional bidders may be awarded Type 2 contracts as competing source contractors for this element. Our objective is to provide some level of planning and funding stability for the Preferred Source, while allowing project management to redirect resources and activities from the Type 1 to a Type 2 contract should the need arise to meet performance, schedule and/or budget constraints.

Type 3 Contracts represent on-going risk reduction activities, vision and architecture development activities, the creation of non-critical hardware or software or the testing of development hardware or software.

Type 4 Contracts will be awarded for special circumstances and needs and will use the more conventional and familiar NSF grant/agreement language and Terms and Conditions. This option assures that any unavoidable contracting problems will not prevent procurement of urgently required activities.

This multi-tiered contracting approach helps university and small business performers to stay involved as the core technology matures and implements a form of rapid maturity for leading edge technology. It is expected that this process will not only improve programmatic performance and reduce contracting risks, but also lead to increased teaming and partnership cooperation within the community. The use of diverse teams that provide the range of experiences needed - for example a university and a commercial software house - will increase the chance that the team as a whole can contribute successfully across all types of contracts. It also means objectives will be defined and measurable, thus reducing program risk and insuring that program goals are achieved.

Pre Qualified Bidders Lists - As a third and significant innovation, we recommend the following method, which will enable timely awards to be made while also assuring the qualifications of bidders for solicitation.

The first step is a Solicitation of Interest in being included on the GENI bid list for a class of work. Responders to a solicitation of interest provide discussion of the background and capabilities being brought to a potential procurement as well as statement of area interest in specific work classes and preferred Terms and Conditions (T&Cs) for such a contract. Lack of adequate qualifications will result in rejection of the proposal, while successful bidders will be classified based upon their stated bid interests

The second procurement action is a Blanket Order Agreement, where a proposed set of terms and conditions appropriate for each bid class as well as the specific language for contract re-direction discussed above (reviewed by NSF prior to release) is finalized. Suppliers wishing to compete on all future GENI procurements within the class will be asked to accept these T&Cs, negotiate necessary changes and then sign the resulting Master Service Agreement. Note that this GENI GPO supplier contract, at this stage, contains no statement of work, budget or schedule of performance, but it is the mechanism by which all work within a class will be contracted.

Successful suppliers are placed on a preferred bidders list for each of the categories of procurement to which they express interest. NSF approval of T&Cs will be a requirement for inclusion on the preferred bidders list. Should re-direction of a contract be required, discounting of the contractor's preference status within the preferred bidders list for a specific class of contract activities will then occur, reducing win possibilities on similar future GENI opportunities. The discounting process will involve NSF, GPO, and Technical Design Coordination Group representation to assure fairness.

The third step is not a separate contract, but rather task orders awarded to successful bidders providing budget, schedule and task requirements for each bid opportunity to which they chose to respond within the class of the Blanket Order.

Impact on Outreach

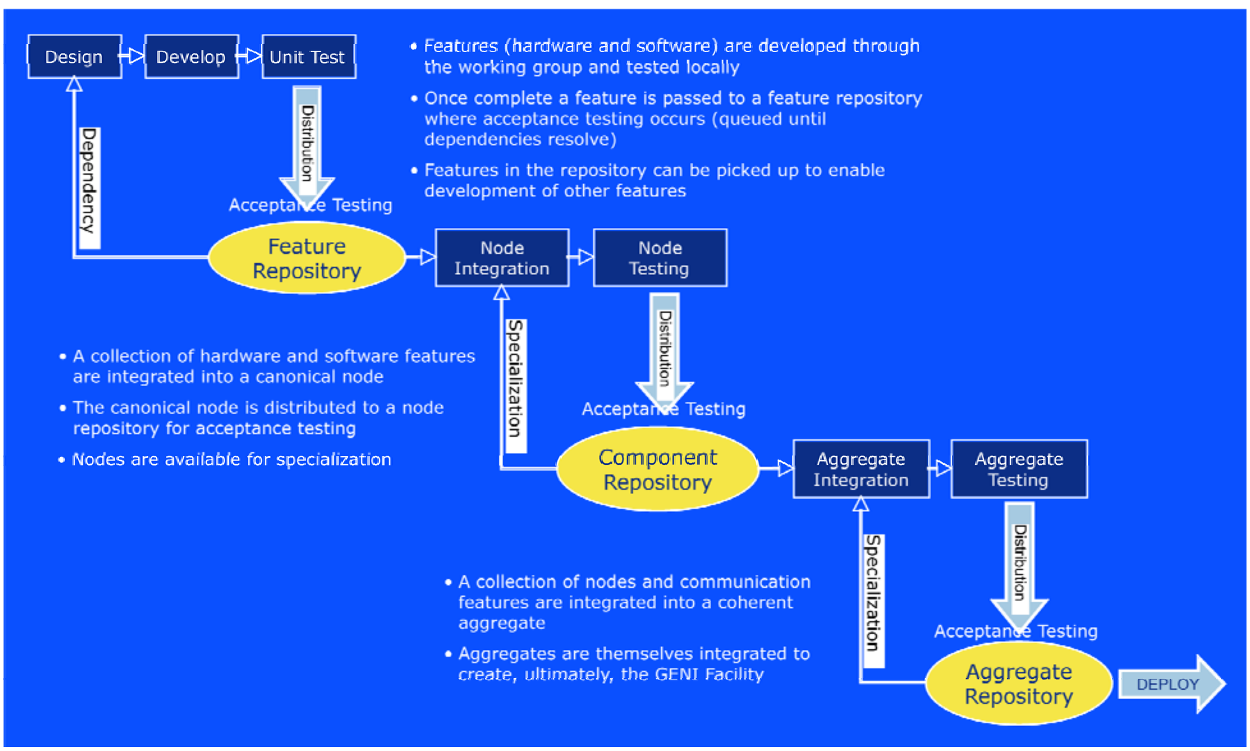
A significant objective of the selection and award process is to ensure that GENI draws from the broadest possible pool of qualified developers and contributors, thus building on the strongest possible technical base. Several specific capabilities of this process directly address this goal. As described above, this sort of contracting encourages organizations with limited financial resources, such as universities and small businesses, to participate in the GENI process by providing financial stability while retaining performance incentives. Contracting thus encourages organizations of all types to expand and improve their capabilities and to move into new performance areas while providing aggressive mitigation of the resulting program risks, greatly increasing the likelihood that new or unanticipated performers will bring innovative capabilities to the GENI table. Finally, contracting like this strongly encourages and rewards University/Industry team formation, leading to new cross-community relationships and overall strengthening of the systems building community.

FFMP contracting model thus serves as a vehicle for outreach. Because members of the Technical Design Coordination Group are drawn directly from the "community of builders" represented by development and prototyping awardees, this outreach immediately strengthens the broad community's participation in the design of GENI, as well as strengthening the community's opportunity to participate in the building of GENI.

3.3.5 Subsystem Build

Contractors will be responsible for delivering sub-systems that meet specified functionality and interoperability requirements. The degree of integration, test and maturity will vary depending on contract and milestone type but will be controlled by the Systems Engineering Group.

3.3.6 System Integration and Tools



Why should integration be the responsibility of the community?

1) Access to a broad set of skills in the community. The GENI facility combines very diverse technologies. Very few organizations contain the expertise necessary to develop "best-of-breed" technologies for GENI.

2) Integration is not mechanical; there are some hard problems.

3) The community will learn about the architecture and its requirements through the process of integrating the disparate parts

GENI represents a new network architecture where "slicability" is pushed to the very lowest levels of the network stack. The process of building GENI will uncover numerous hard research problems. Certainly community-based component development will uncover many of these problems. However, the process of integrating multiple disparate components will uncover broad design principles necessary to create innovative network architectures.

4) The community will be more invested in the testbed if it is responsible for more of its construction.

To build the most useful testbed possible, GENI must treat its users as co-developers of the technology. The community of users knows best the list of required features, where the code must be solid and where it does not, and when it needs to be delivered. At the same time, the community of users needs to understand (and be invested in the decisions) engineering tradeoffs required to deliver a set of features on a schedule.

5) The community can actively demonstrate the prioritization of requirements by commiting to complete integration tasks. * What examples do we have of community-based integration?

Kernel development for Linux involves integration of many separately developed components.

The Apache Software Foundation includes a number of disparate projects that are intended to work together.

* What tools/processes can we apply to simplify integration?

Apache Foundation (http://www.apache.org/foundation/how-it-works.html)

The Cathedral and the Bazaar (http://www.catb.org/~esr/writings/cathedral-bazaar/)

The open source development community is replete with examples of community-driven component development and integration projects. One of the key lessons learned is that a consistent, common development process facilitates community contributions.

The development process can be broken down into three parts: <<something about an organizational structure that motivates high quality contributions>>, development tools, and communication tools.

Clearly community-driven projects must accommodate diversity in expertise, style, and motivation. Open community feedback is central to ensure that code meets appropriate standards for efficiency, reliability and maintainability. The implication is that the development process must be open at all stages with code, documentation, tests (and test results), specifications, requirements etc available for public comment. The other implication is that tools for community communication are necessary. Mailing lists, wikis, and virtual meeting rooms are tools used in existing open development projects.

In addition to open communication, a common development tools ensures that the basic development process can be shared. To facilitate the development process GENI must provide shared facilities for source code and document managaement, defect and issue tracking, and testing. Further, common libraries, for example for logging and error reporting in the running system, will simplify downstream maintenance.

Accommodation must be made in the GENI development process for non-software components and integration tasks that incorporate both hardware and software components. This problem is not unlike management problems in large datacenters where software and hardware management are frequently tied together. In order to represent formally the relationship between hardware and software, datacenter administrators use modelling languages such as the

DMTF Component Information Model

(CIM). CIM is useful for automating many management tasks, but is limited in expressiveness. The new Service Modelling Language http://www.microsoft.com/business/dsi/serviceml.mspx) extends the capabilties of CIM to describe through formal specification constraints on the construction and deployment of integrated components. Further, SML tools can be included during software (through statement annotation) and hardware development (through builtin hardware models and dynamic hardware monitoring). Since SML models are just XML documents, they can be placed under version control and subject to the same community scrutiny as more traditional software packages.

3.3.7 Testing

Testing GENI components presents a unique problem. In many ways, it is similar to problems incurred by enterprise IT when managing a globally distributed infrastructure: adequate pre-deployment testing is important to ensure that business critical systems continue to function correctly, but creating a realistic environment in which to test large-scale, distributed applications is expensive and time consuming.

In GENI we plan to ensure the quality of applications through automated and manual testing at several levels. The unique aspect of our plan is that we intend to use GENI itself to ensure cost-effective testing at scale.

Testing occurs at three different levels. The first level is developer-driven unit testing. We expect component developers to conduct rigorous developer testing prior to submission in the public repository. This is standard developer practice and applies to both hardware and software components.

The second level of testing will be automated regression testing performed through the source repository. As part of the development process, subcontractors will be required to provide automated regression tests that can be executed within a centralized GENI Test Facility (GTF). The GTF is similar to test environments used by existing enterprise IT administrators. In this case, the GTF will be a complete GENI facility using emulated networking and simulated workloads to create a controlled and repeatable test environment. In order to incorporate test hardware easily, it will be necessary to tunnel traffic to remote locations as well; that is, the GTF must be able to configure external

The GTF will be scheduled on a time-sliced basis. A developer provides a configuration (or uses standard configurations that the Systems Engineering Group provides) that describes the recipes used to configure the hardware resources, a network topology, and a particular workload. For example, a developer testing a software package can embed that package inside a standard edge node kit or inside any distribution found in the software repository (to support integration tasks).

The final level of testing will occur in the GENI Facility itself through an “alpha” and “beta” process. The “alpha” and “beta” facilities are slices of the deployed testbed. That is, we are using the sliceability of GENI to enable relatively stable testing at scale and with a realistic workload. The “alpha” slice will consist of a set of physical resources while the “beta” slice will share physical resources with the production network.

4 Project Management

This section of the Facility Construction document provides an overview of GENI project management as envisioned by the GENI Planning Group and, in particular, the Project Management Team assigned to develop the basic management concepts, requirements, processes, and organizational structures that will be required to manage GENI during Facility construction. A detailed account of the work of the PMT can be found in two GENI Design Documents [GDD-06-034, GDD-07-xx], both prepared during the Conceptual Design stage of project planning. This section of the Facility Construction document draws heavily from these two GDDs and the reader is encouraged to consult them for further detail.

The following subsections describe the project management paradigm in layers, starting from a brief reminder about the unique nature of the GENI construction process itself (Subsection 4.1), then move to a discussion of the critical processes and procedures that must to be enabled for both strategic as well as day-to-day management (Subsection 4.2). We then talk about the organization structure and the functional requirements of the GENI Project Office that will be necessary to carry out the ongoing work of management (Subsection 4.3) and, finally, we apply the results of each of the above subsections to an overview of operations during GENI construction (Subsection 4.4).

4.1 Construction Management Overview

We start our presentation of GENI project management with a discussion of some of the unique features of the GENI project and, in particular, the paradigm that will be followed for the construction of the GENI Facility. This vision for Facility construction – which differs significantly from that of other MREFC-sponsored projects – establishes the baseline for project management.

The GENI project faces a complex array of challenges, many of which are rooted in high importance, yet competing, requirements. The magnitude and visibility of the project argues for the application of structured, “heavy-weight”, management processes and tools to ensure that schedules are met, costs are controlled, milestones are achieved and deliverables are indeed delivered. Yet, another very high priority requirement is that GENI is about innovation by a research community that is accustomed to lightweight processes, rapid changes in direction, and an adaptive, agile approach to facility construction. These two perceptions are diametrically opposed and must be continuously balanced.

Our project management plan is focused on finding the balance between these different characteristics. These key characteristics led to the design of project management processes that provide agile, light-weight management structures and processes that are amenable to rapid change and responsiveness to disruptive innovation from the GENI community, while still providing the management controls and determinism needed to ensure schedule and cost control for the overall project. Therefore, our overall project management approach includes processes and procedures to dynamically balance cost and benefits, and make needed information visible to the technical teams *at the natural time scale of the technical development*.

We next consider the structure of the GPO. It is trivial to simply assign each of the functions to an office, and declare the task complete. However, several characteristics of the GENI program suggest that this decision should be considered carefully. These include GENI’s “use-it-as-you-build” approach, implying that GENI’s design, architecture and implementation will continue to evolve during all life-cycle phases; the necessity that GENI be built by a number of teams of differing background and experience; and the recognition that GENI is not a standalone instrument, but rather will benefit from interaction with a number of players outside the control of the project management team.

4.1.1 Management Requirements and Design Concept

Project management for GENI construction requires that several *functional areas* be developed in order to provide project management requirements on a continuing basis. These include – *but are not limited to* – the following areas:

Technical Design Coordination Group

While individual Construction Teams are responsible for the development of specific GENI components and subsystems, technical direction for the project as a whole will come from a Technical Design Coordination Group, which includes key staff from the GENI Project Office, representatives of the Construction Teams, representatives of the GENI Science Council, and additional individuals chosen for their expertise.

Systems Engineering: Systems engineering is at the heart of the technical part of this project and project management must be able to carry out this function effectively. The Systems Engineering function is responsible for defining the architecture and technical roadmap for the

GENI facility—taking into account the requirements of the research community, the latest available technologies, and the realities of the construction process (e.g. budgets, engineering challenges, schedules, etc.). Decisions about development priorities, phasing, schedule and targeted functionality will be greatly influenced by the Systems Engineering function. Once specifications and SOW's for contracted work are developed (see below discussion of contracting), SE will also be responsible for working with the community of builders for systems integration, acceptance testing, and deployment. As described in Section 3.3.6 , inherent in the development of individual platforms and related software by contractors to GENI, will be integration, test and fielding. The *Systems Engineering function within the project management office will have responsibility to ensure that core critical component elements built by vendors meet robustness and supportability requirements.* This will require that there be a Systems Engineering function that is able to develop requirements and specifications for network components; test these components (both individually and in a network environment) in the laboratory; and deploy proven network platforms (hardware and software) to the field. After field deployment, this systems engineering function must be able to maintain and provide upgrades to the GENI Facility, and even assist in the instruction of network users on the use of the Facility for research and education.

Financial Management and Control: Effective financial management is critical to the success of the GENI project. This functional area addresses tasks in the areas of financial planning, budgeting, accounting, financial procedures and control, documentation and records, as well as financial reporting.

Legal: Legal services must be available during all phases of the project, but particularly during construction. It is expected that more than two-dozen contractors will be involved in the development and deployment of the GENI Facility. This will require contracts and numerous other legal documents to protect the assets of GENI as it is developed. In addition, intellectual property must be protected, cooperative agreements developed, and compliance with local, state and federal requirements met.

Project Operations: Several activities within the area of operations will require regular management and leadership during the course of the GENI project. These include: project planning, scheduling, and tracking; supervision of contractors during construction; management of GENI Facility node sites; maintenance of installed equipment; reporting on project progress; and several other related tasks.

Liaison & Communications: The GENI project management office will be required to interact with a broad range of organizations and individuals – both inside and outside of the GENI Project. For this reason, the Project Management Team believes that project management must have an organization that is dedicated to the role of "liaison and communications" – with industry, government, federation partners, university researchers, educators, as well as the general public and others.

Administration: Administration of the GENI project will fall to the project management office. At the highest level, this will include services to the Project Director and the Project Manager, but also included supervision of satellite operations; direction of human resources services, including salary administration, benefits, etc.; capital procurements; plant safety; and various administrative services.

4.2 Processes & Procedures

The second element of the GENI project management stack is made up of the key processes and procedures that will be used to manage work during GENI construction. In the subsections below, we describe three of the processes that are central to GENI management. These are: 1) risk management 2) change control management, 3) project management control systems.

Our focus on processes and procedures are in the context of *Life Cycle Management.* As we discussed in Section 3 we build on the open-collaboration rapid-iteration system development model. Under this model, construction will occur through a series of continuous build, test, integrate, release, maintain and extend loops.

If we view processes and procedures as existing to support the Life Cycle of construction then we see that processes such as change management and risk management are not isolated but are rather part of a holistic system. Change Control is vital as it manages the gamut from small bug fixes to new feature enhancements and is informed by priority setting and trade off analysis. Similarly, risk management goes beyond a mechanical calculation of risk (though this is important part of baseline budgeting) and instead becomes a tool to turn risk into opportunity. Finally all of the processes and procedures are adapted to accommodate contributions from the community and partners.

4.2.1 Risk Management Plan

The fundamental goal of the risk management plan is to minimize project risk and maximize project opportunity - the potential for success of the project. It is critical to recognize that the appropriate definition of project success is broad. While the managerial goals of delivering the expected functionality to the user community, on schedule and on budget, at each milestone point during the five year build cycle is a central element of any successful GPO, the PMT team views our objective as insuring that GENI will, at minimum:

- provide a high impact, effective vehicle for research;
- receive continuous, broad and enthusiastic community support;
- provide transparent and effective project, capability, schedule, and budget management;
- offer significant broader impact to NSF's stakeholder communities.

To accomplish this objective, we focus on design and prototyping as the fundamental vehicles for risk mitigation and opportunity maximization, casting the entire development and prototyping cycle within a risk mitigation / opportunity optimization framework. In broad outline, our framework is a flexible, agile planning, development, and assessment process intended to a) draw on world-class talent, whether found in academia, small business, or large industry, b) continuously and iteratively advance the design of GENI towards a lowest-risk, highest-return solution and c) deal with the numerous non-technical risks discussed below. We further plan to retain and exploit these prototypes, not only prove feasibility and reduce technical risk, but also to reduce integration and downstream GENI operations risks wherever possible. Essentially, our development and prototyping program becomes Phase 0 of an overall construction and operational deployment plan, delivering immediate value to the customer research community to quickly build experience and confidence in GENI's capabilities and progress.

Our approach for identifying and managing technical risks is rooted in the design and development process used to create PlanetLab, one of the most successful distributed systems research facilities constructed to date and a direct precursor of GENI. PlanetLab today spans some 335 sites in 35 countries, supporting the design and evaluation of dozens of long-running services that transport an aggregate of 3-4 terabytes of data every day, satisfying tens of millions of requests involving roughly one mission unique clients and servers.

PlanetLab's design process is characterized by two key elements:

- **Experience-driven Design.** PlanetLab's design evolved incrementally based on experience gained from supporting a live user community since its inception. This is in contrast to most systems, that are designed and initially evaluated under controlled conditions, contained within a single organization, and modelled using synthetic workloads.

- **Conflict-driven Design.** The design decisions that shaped PlanetLab were responses to conflicting requirements. The result is a comprehensive architecture based more on balancing global considerations [managing risk/opportunity tradeoffs] than improving performance [mitigating risk] along a single dimension, and on real-world requirements that do not always lend themselves to quantifiable metrics.

These elements are supported by a development and construction staging procedure that provides two supporting attributes: the system must provide some level of useful capability very early in its development, and the development methodology must operate in a manner that supports continuous evolution and introduction of new capabilities.

To form the full Risk Mitigation Plan, we augment the PlanetLab development model with additional key processes and procedures. These include

- A lightweight, yet rigorous and structured, method for capturing, evaluating, and cataloguing specific project risks and opportunities in terms of impact and cost, to ensure that inputs to the risk mitigation process are well defined and visible to all potential members of the GENI development community. This ensures that risk mitigation and opportunity maximization becomes a community-wide activity, rather than a narrowly focused GPO-only exercise.

- A set of objective decision support tools, to assist program managers and the development community with reasoning about priorities and tradeoffs. Such tools are particularly valuable when tradeoffs must be made across different classes of risk.

- A unique and innovative contracting framework for the development and prototyping activities that form the core of the GPO's activities in the initial phase, and apply equally to the construction phase. This contracting framework, creates powerful incentives for innovative and effective contractor performance, while simultaneously facilitating access to GENI contracts for universities, small business, and historically underrepresented organizations, thus ensuring that GENI's development and construction efforts draw on the best talent wherever it is found. Within the proposed process, contract risk mitigation is embedded, providing not only methods to better assure contract performance but also a funding strategy that is fully quantified.

Taken together, these processes form a full risk mitigation and opportunity capture plan that integrates the formal capture, assess, mitigate, evaluate cycle of a standard risk mitigation plan with a proven development model for complex, research-oriented software-intensive systems to create an approach precisely customized to the GENI project's requirements.

4.2.2 Change Control Management

Change is an expected and desirable aspect of GENI construction. Change is a natural outgrowth of GENI's "use-it-as-you-build" approach, implying that GENI's design, architecture and implementation will continue to evolve during all life-cycle phases; the necessity that GENI be built by a number of teams of differing background and experience; and the recognition that GENI is not a standalone instrument, but rather will benefit from interaction with a number of players outside the control of the GPO. In this *dynamic project environment* the GPO will frequently influence decisions by the technical teams, and technical teams resulting in changes and outside entities will frequently make decisions that affect change control management. For this reason, we target agile, light-weight management structures and processes that are amenable to rapid change and stretching, while still providing the management controls and insights needed to ensure schedule and cost control for the overall project. It is vital that change control processes and procedures dynamically balance cost and benefits, and make needed information visible to the technical teams *at the natural time scale of the technical development*

Change is inherent in the software development model for GENI. As described above, GENI construction will be employ an "open source development model", or OSDM. In the context of change control , it is important to understand that the OSDM is *not* simply a statement about availability or cost of source code, or selection of a particular software license. Rather, OSDM is a rich project management model that has produced such successes as the Linux operating system, the industry-dominant Apache Web Server, and the highly complex GNU C/C++/Java compiler and programming tools. [2] OSD change management addresses such issues as:

- How the project is managed and coordinated.
- How change control is addressed, and how developers submit new code and documentation.
- The process for defect reporting, triage, repair, and verification.

---

[2] That these successes were achieved under the conditions of tight budget, geographically distributed and loosely coordinated design and implementation teams, and heavily volunteer workforce makes the case for this model in the GENI context even stronger.

• Standards for building, packaging, testing, and releasing new versions.

• Information dissemination paths for announcements, developers, users, documentation, and collateral materials such as project websites.

• Tutorials and FAQs to help new developers get oriented and learn how the development team works.

Because the OSDM is still emerging, however, it is neither as widely understood nor as well integrated into traditional project management tools as are more classical software development models. Thus, we will employ processes that adapt the OSDM model to the specific needs of GENI software development and the GENI program, while also integrating this software development management and change control model into the larger context of overall GENI program management.

Change Control Management is described briefly here and then in more detail in Appendix B as well as the GDD.

Change Control Management Process: Closely related to the PMCS process is that of Change Control Management (CCM). This process must be able to respond with a minimum overhead to changes in the project plan – whether unplanned or planned. Ideally, planned changes should be addressable directly by the change initiator (e.g., Working Group). That is, the change initiator should be able to determine the impact on cost, schedule, resources, etc., without outside assistance. It should then be able to make change recommendations to project management, have these *immediately available* to other project team(s) as well, where impact can be determined, and address recommendations following lines of authority within the organization. Based on this, the total impact of a planned change should be able to be assessed quickly and approved, or not, with visibility to the entire project team. Unplanned changes should be addressable in a similar streamlined manner.

4.2.3 Project Management Control Systems

Project Management Control System: The development of an effective, computer-based and networked Project Management Control System (PMCS) will also be a key responsibility of the GPO. This PMCS must be useable by all project participants for project planning, budgeting, scheduling, monitoring, tracking, responding to risk events, and documenting project progress. In addition, the tool – which may be several individual tools that are integrated so that they act as a whole – must also allow collaboration and information-sharing among project participants. All of the functional responsibilities must be integrated into the PMCS selected by the GPO, and be consistent with all other management processes and procedures as represented by the Risk Management Plan, IMP/IMS, EVM, CCM, WBS, and others that might be developed by the GPO during the course of the project.

Our experience and that of other MREFC projects such as those presented at Project Science (www.projectscience.org), leads us to recommend that a Project Management Control System be constructed by integrating a number of reporting and visibility tools. Integrating these tools to create a operational view of the project organized around a dashboard that provides a stop light chart and allows drill down on the health of the key activities is recommended. It is important that such a dashboard be compatible with virtual collaboration tools so that the information in the dashboard can be dynamically updated by all project members and sub-awardees. Not only should the dashboard be used by project members and contractors but it should also provide real-time transparency to the NSF, GSC, industrial partners and other members of the community.

Tracking schedule and expenditures are an important aspect of construction and will be particularly challenging given the dynamic nature of the requirements, prototyping and deliverables. The schedule, milestones and resources defined in the WBS will be managed using Microsoft Project and associated tools. As in many existing MREFC efforts we expect that it will be necessary to support and customize the tools and processes that contribute to a PMCS environment. Earned Value Management will use WBS elements to assign value metrics and percent completion will be assigned at regularly scheduled management reviews.

The GENI Project Manager will be also be responsible for working with the SE functions and the technical community to refine Risk Management, Change Control and Contingency budgets. Initial management plans for each of these key areas are in described elsewhere in this document.

PMCS must provide transparent distributed insight into IMP, IMS, EVMS, actuals to date and planned, and a weekly Risk Watch list. Any activities which are not in expected range at the weekly meeting should be flagged for follow up and reporting at the next weekly meeting. Corrective action and process changes must be implemented as part of these processes and in response to the weekly reviews.

For management and collaboration we recommend the use of a commercial Advanced Collaboration Environment tool such as PTC Windchill (http://www.ptc.com). This tool also allows inter-linking of ACE tools in different organizations and is recommended that project management evaluates a plan to deploy an ACE server at NSF itself (or link to an existing ACE if it exists) to provide visibility for the NSF Program Directors into GENI project management . For management of academic researchers who are doing prototype development, it is recommended that they not be forced to use heavy-weight processes and tools that they are not accustom to using. Instead, the PMCS tools and processes should leverage web technologies (e.g., XML, XSLT, etc.) to integrate tool-sets using these technologies, to create a simple to use web-based tool that allows developers to report progress and status for reporting in EVMS and other PMCS functions. This same tool can provide visibility to the entire community into the overall progress of development projects. This tool thus can serve as an "***Operational Dashboard***". Using a distributed collaboration environment with contractors can give them the ability to "deposit" architecture and design artifacts related to their deliverables and milestones.

4.3 Facility Operations in Construction

Here we deal with the <u>operations plan</u> in the construction period. We've been building toward this by defining the organization, the principal processes, the general guiding principles, etc., but now we need to specifically lay out the way we expect operations will go during the construction period; we really have not addressed this issue before in any significant way. Here are some subtasks that we should consider (below).

During the 5-year period of Facility construction, GENI will be used by the research and education communities and managed by the GENI Project Office. This period of operation will be similar to the full operations period that will follow the completion of the Facility. There are, however, important differences between operations during construction and full operations after construction. We take up a discussion of these in this final section of the Facility Construction Plan.

4.3.1 Deployment and Provisional Commissioning

The idea of "commissioning" is more of a process than an event. Under this model commissioning is not a "final" event at the end of each stage rather it is a continuous process of functional releases that "gives the thumbs up" for the facility to continue operations. Thus, commissioning can be viewed more broadly, so that it includes integration testing, lots of contributions from the community and an open source based development model that validates that each component works properly in the context of the facility.

Appendix 1 GENI Risk Management Plan

All projects require some level of risk management. In smaller, self-contained projects, the risk management process is most often *ad hoc*. In a project of the size of GENI, risk management is a well-defined, formalized process that can occupy the efforts of numbers of managers and scientists alike in engineering, finance, manufacturing, and operations. Whether the risk management process is small or large, however, the objectives are the same – to effectively utilize budgeted funds; to guard against the potentially disastrous impacts of technical, cost and schedule slippage; and to maximize the probability that the final product of the project meets the requirements of the communities it is intended to serve.

The GENI Risk Management Plan is described in detail in GDD-07-0xx; the reader is referred to that document for a discussion in greater depth. Here we want to focus briefly on a few steps to provide an overview of the risk management process, particularly as it applies to cost estimation and overall project budgeting during the *conceptual* design phase. The Risk Management plan during this phase is based on an approach from other MREFC projects and is based on past experience from those communities as adjusted for use in this project. We believe that at a conceptual design stage the wealth of experience in the MREFC communities is suited for this effort. However, we expect that the model, will continue to evolve and will be further adjusted to reflect the experiences of other large-scale software intensive networking projects during construction.

At the same time that end-game risk is reduced by a use-during-construction paradigm, risk is folded into the construction process itself. It is this risk that GENI's risk management plan is intended to address. In order to do this effectively, two principles must be kept in mind. The first is that there is positive value to risk. The second is that risk is not a spectator sport; risk management, although there must be assignments of final responsibility, must be embedded into the culture of the project. Risk management is everyone's job.

Risk is essential to the success of a project like GENI. To eliminate risk would mean that GENI would only build what it knows precisely how to build today. This strategy would surely result in a product that would be outdated from the start. On the other hand, the acceptance of risk that can be effectively managed will create *opportunities for innovation* in the Facility being built. It is for this reason that GENI will be used by the computer sciences communities during construction – to identify errors in initial designs and to uncover new uses and technologies that the facility should incorporate.

The second principle, that risk management should be inculcated *into the whole culture* of the project is consistent with the overall strategy for project management. The fact that risk management will be everyone's business, however, does not mean that there will not be a formal risk management responsibility assigned within the project. The hierarchy for those assignments will be outlined below.

Risk Management Approach

Risk management is not a new science. It is – and has been for many years – an integral part of project management. Many approaches have been developed for risk management, so there is no need to reinvent this process – only to adapt it, as required, to the particular project at hand.

By convention, a well-developed Risk Management Plan incorporates several well-established steps. These include:

- Identification of the principal risk elements most likely to be associated with project tasks;
- Organization of these risk elements into a few simple categories that can be applied to different project tasks;
- Assessment of the potential impacts (or consequences) of these risks on project tasks and the likelihood (probability) of their occurrence;
- Development of a formal method for the quantification of the risk elements so that the quantitative impact on cost, schedule, etc., can be projected. This process generally involves the definition of a set of Risk Factors (RF) that are associated with the impact of a particular risk. It also involves the definition of the likelihood that each risk type (and its associated RF) will occur;

- Establishing a rule for the application of multiple categories of risk to each project task (i.e., it is not unusual for any given task to have risks associated with cost, schedule, design, etc., associated with it);

- Identifying mitigation (risk reducing) strategies that will help to bring the overall risk impact down, and finally;

- Development of a risk management organizational structure as well as the processes and procedures for tracking, reporting, and mitigating risk as the project proceeds.

For the Conceptual Design stage of planning, we have grouped a multitude of risk elements into three principal categories: 1) Technical Risk, 2) Cost Risk, and 3) Schedule Risk. There are, in addition, two others – Programmatic Risk and Project Objectives Risks – that will not be discussed here [cf. GDD-07-0xx]. Based upon prior use and the experience of other large MREFC projects, GENI has adopted a scheme for assigning risk factors (RF) and probabilities of occurrence (*Multipliers*) to risk elements in each of these three categories. This grouping is summarized in the following table.

Using the information in this table, we can calculate a Risk (R) for each project task in the GENI project. The risk (R) is simply the sum of the products of the risk factors (RP) for each risk category and the probabilities of their occurrence. This calculation has been built into Cost Estimate Detail spreadsheets for GENI WBS tasks [cf. GENI WBS Document]. The risk (R) is used to calculate a contingency budget that, when combined with the Cost Estimate budget, makes up the whole of the GENI project budget.

As GENI moves from the Conceptual Design stage to the Preliminary and Final Design stages, the strategy used in the calculation of the contingency budget will be applied to scheduling. Also, additional risk categories will be used to account for risk associated with programmatic and final project goal issues. We now move into the topic of risk mitigation.

Risk Factors & Multipliers	Risk Factor Descriptions
	Technical Risk Category
1	Existing design and COTS hardware
2	Minor modifications to an existing design
3	Extensive modifications to an existing design
4	New design wihin established product line
6	New design different from established product line. Existing technology.
8	New design. Requires some R&D development but does not advance the SOA
10	New design. New development of new technology which advances the SOA
15	New design way beyond the current SOA
Multipliers	
2%	Design **or** manufacturing concerns only
4%	Design **and** manufacturing concerns
	Cost Risk Category
1	COTS or catalog item
2	Vendor quote from established drawings
3	Vendor quote with some desig sketches
4	In-house estimate for item within current production line
6	In-house estimate for item with minimal company experience but related to existing capabilities
8	In-house estimate for item with minimal company experience and minimal in-house capability
10	Top-down estimate from analogous programs
15	Engineering judgment
Multipliers	
1%	Material cost **or** labor rate concern
2%	Material **and** labor rate concerns
	Schedule Risk Category
2	No schedule impact on any other item
4	Delays completion of non-critical path subsystem item
8	Delays completion of critial path subsystem item
Multiplier	
1%	Used for each of the three risk factors in the Schedule category

Table 1: Risk Factor Descriptions

Risk Mitigation Strategies

Risk mitigation is the set of strategies that might be used to reduce overall risk to the project. And again we consider the risks just for technical, cost, and scheduling components of the project and leave programmatic risk until the next planning stages.

There are four major categories of risk mitigation. These include: 1) Risk Avoidance, 2) Risk Control, 3) Risk Assumption, and 4) Risk Transfer. Earlier in this discussion, the area of ***risk avoidance*** was mentioned. This strategy, while it will apply to some parts of the project, such as conservative selection of network platform technologies, is not a strategy that will apply broadly across the project. Risk avoidance reduces risk by selecting technologies, processes, designs, etc., that are generally well-tested and considered to be "legacy". Broad use of this risk reduction strategy would leave GENI outdated almost from the start of construction. This is not a strategy that will be widely used in GENI.

In the case of ***risk control***, a known potential risk event (or class of events) is managed so that its impact is reduced if the event should occur. Here, project participants will have identified the risk before facility construction starts and will have developed a strategy for its management (mitigation) and accounted for the risk in the cost estimate of the project. The Planning Group feels that this category of mitigation is likely to be the most frequently used during construction. The details of the mitigation process will vary from task to task and will be specifically defined during the Preliminary Design and Final Design stages.

The ***assumption of risk*** involves a conscious decision to accept certain risks and their consequences to the project. This is not truly a mitigation strategy, but it will occur during construction, with decisions made by the GPO on a case-by-case basis.

Risk transfer will be a central component of the GENI strategy to reduce the consequences of risk events to the project. This will be accomplished by means of conditions incorporated in contracts with facility builders. Details of this process will be addressed by the legal and contracts functions of the GPO as contractor bids are accepted and contract awards made.

Construction of GENI will require an application of innovative risk management. Below we briefly describe an approach to risk mitigation through funding.

A Risk Mitigation Funding Plan

An important aspect of any risk mitigation plan is the determination of risk mitigation and protection (contingency) funding levels required. In this approach, risk contingency funding directly supports the contracting model described in Section 3.3.4 , providing a critical linkage for the risk mitigation plan.

The familiar process of funding estimates for risk mitigation is to use the probability of occurrence and the impact of full realization of the perceived risk to derive a task funding percentage for risk mitigation. While reasonably reliable when applied to programs facing large sets of risks that have been encountered in past activities, the standard methodology is less accurate when applied to programs such as GENI where there is limited track record and high technical risk.

To address this matter we conclude that it is necessary to augment the standard estimates with additional information that takes into account the many proposed innovations in contracting and teamwork support. For example, for Type 1 (leader) and Type 2 (follower) contracting on a specific task, a last decision point for contract redirection will have to be agreed on, as will funding requests within the bid for the follower role (solicited as part of an industrial bid). Our past experience provides confident starting estimates, but these estimates will need tailoring for each specific situation due to the cutting edge nature of most of this work. The PMT believes that the last redirection point for most work is ~20-30% of funding spent while follower (Type 2) funding profile will normally be at about 50% of the Type 1 contract. This model implies the ETC is about 115% of Type 1 acceptable bid cost if the Type 1 contractor successfully proceeds to completion. For contract redirection at 30% spent, worst successful case would imply <130% of successful contract cost, assuming similar cost proposals from the leader and follower contractors. Schedule overrun estimates would be assumed to be similar within this model. An additional refinement is required because industry and university labor rates differ significantly in many cases, implying further (but precisely known) expectation adjustment when an industry contractor backs a university bidder.

While our model predictions are not fully substantiated at this time, we assert that with some initial experience, prediction accuracy for funding risk mitigation will be much *better* using this approach than the more traditional probability/impact model. This improvement in contingency prediction has been demonstrated in past practice. However, until this is firmly demonstrated in the GENI context, the PMT proposes to use both methods and reconcile the difference in prediction, reviewing the results with NSF and GSC prior to any build cycle contract award or activation of any functional milestone.

Risk Organizational Structure

Although the organizational structure of the GPO has not yet been finalized, it is anticipated that the GPO will include at least the following functions: 1) Senior Administration, 2) Systems Engineering, 3) Financial Management and Control, 4) Legal, 5) Operations, and 6) Communications. It is the intent of the GENI Planning Group that risk management becomes a formal responsibility within each of these functions, with final and active responsibility for this effort assigned to the GPO project manager (PM). It will be the responsibility of the PM to develop the details of the Risk Management Plan and to actively administer that plan throughout the course of GENI Facility construction. Part of this responsibility will include the inculcation of a culture of risk management awareness in all project participants, including researchers as well as contractors. Other specific responsibilities will include: 1) formal development of a set of risk management policies to guide project staff before and during risk events, 2) development of risk response and reporting procedures, including (at least) monthly formal reports to the senior management (e.g., risk matrices, watch lists, etc.), and 3) integration of risk management processes into the Project Management Control System and its associated electronic communications systems. It is planned that this work will begin during the Preliminary Design stage and then be refined during Final Design planning. Details of a preliminary (Conceptual Design Stage) plan for the organization aspects of risk management are included in GDD-07-0xx.

Appendix II Change Control Plan

Change is an integral part all large projects – whether planned or not. For GENI, change is expected to be the norm; it will be the natural outcome of the *use-during-construction* paradigm being implemented in the project. However, knowing that change will occur does not guaranty that it will be orderly or well-managed change. Thus, there is a need for a carefully planned Change Control Management process – a process that will ensure that changes to the facility design, in the choice of technologies, in the method or schedule for construction, and/or in the budget – that will effectively implement change with the minimum disruption to the overall project. We outline the Change Control Management process for GENI here; additional details can be found in GDD-07-0xx.

Change Control Management (CCM) is a formal process, built around an organizational structure and well-defined procedures. It is a method by which changes of various kinds to the project are formally defined, evaluated, and approved prior to implementation. It directly involves the principal project stakeholders, including senior management, project engineers, Facility users, financial and legal managers, as well as project contractors who have received awards to construct the Facility and all of its components. CCM also involves formal reporting responsibilities that become documented in Engineering Change Notices (ECN), revisions of facility requirements and designs, updates to the project schedule, and reports to the communities of users as well as sponsoring organizations. Finally, whenever changes occur, it is a human activity and this fact must be explicitly recognized in the development of the policies and processes that guide changes within the project.

Core Principles: GENI Change Control

In the early pages of the GENI document on Project Management [GDD-06-034), the GENI Project Management Team (PMT), one of the several Working Groups assigned to develop different aspects of the GENI project, outlined four core principles for GENI management. These were: 1) adaptive flexibility, 2) trust and transparency, 3) collaboration and fate-sharing, and 4) innovation. Without going into any detail about these principles here, it is important to recognize that these same principles apply directly to the CCM process.

First of all, because change is expected in the course of GENI's implementation; project management must be able to adapt effectively to such change through the CCM processes. The implementation of changes through the CCM, however, must occur in such a way that there is minimal impact on the performance or availability of the GENI Facility during the change implementation.

Secondly, anticipated changes must not only be visible to the entire community affected by the change (i.e., GENI management and staff, project sponsors, research users, and facility construction contractors), but the communities must have an opportunity to participate – at some level – in the decisions concerning changes and in their scheduling.

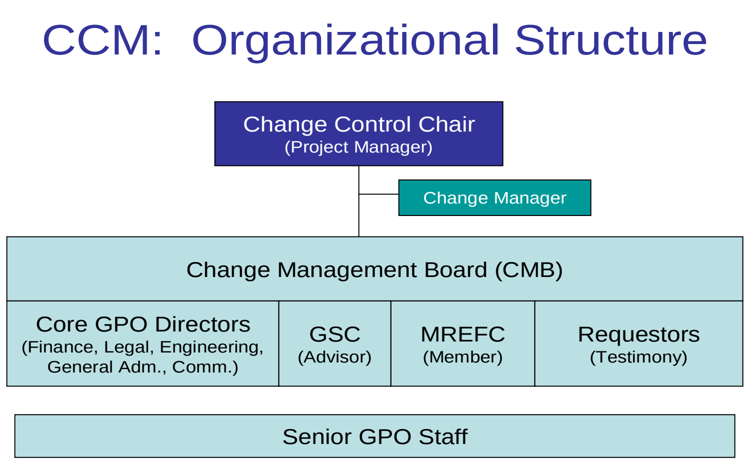
Thirdly, change decisions must also be based on business considerations. In the case of the GENI project, this refers to operating within the allocated budget, maintenance of the construction schedule, and protection of the ultimate performance and functionality of the GENI Facility.

Change Control Management Organization

In order for the Change Control Management processes to work well, there must be a well-organized CCM organization within the GPO to address change requests. *Within the GENI project, change control management will be the direct responsibility of the GPO Project Manager.*

The PM will be responsible for the appointment of a Change Management Board (CMB) that he/she will chair. This board will be composed (at least) of: 1) the core set of senior managers of the GPO functional units (in the GPO Reference Design, this includes the heads of finance, legal, general administration, systems engineering, and communications); 2) a representative from the GENI Science Council; 3) selected senior professional leaders from GPO functional units; and 4) representation from the MREFC for change requests that have the potential to impact project cost, construction schedule, or facility performance/functionality in a very significant way (details of this to be established during the Preliminary Design stage). It will also be important that there be established a way for the GENI research user community to have a voice in changes and their deployment timing.

The Project Manager will also hire a Change Manager (CM) – reporting directly to him/her – whose responsibility it will be to manage the day-to-day CCM process, including interactions with all project personnel affected by the change process. It will also be the responsibility of the CM to distribute in a timely way information related to change control by means of the GENI PMCS process. During meetings of the CMB, technical and/or administrative staff originally responsible for a RFC will be present to "testify" related to their change proposals.



Once the CMB has been formed, the PM will appoint a CMB secretary, who will be responsible for development, maintenance, and timely distribution (via the CM) of the proceedings of CMB meetings and decisions. Final decisions related to approved-changes will be communicated throughout the project by means of the PMCS. Those changes that directly affect contractors and contract-related issues will be communicated to contractors through the office of the Project Manager and his/her designates in GPO functional units (e.g., contract administration, legal, systems engineering, etc.). This process of information dissemination must allow sufficient time for response from the broader community before a change is implemented. It will be the responsibility of the PM to ensure that there is an appropriate mechanism in place to accommodate community response and discussion.

Change Control Processes

The actual Change Control Management process is made up of a number of steps. To start, it involves the recognition of the need for a change in some aspect of the facility – its design, technology, construction, or research use. This leads to a formal Request for Change (RFC) made by some member of the community of designers, builders, users, etc. The RFC must be received by a member of the GENI management, logged, and evaluated to determine its feasibility within the broad scope of the project. There must then be a formal process for the approval of the proposed change. Finally, there must be an orderly process for implementation of the change and a follow-up process that documents and archives the change as well as determining the impact of the change and any influence this change might have on planned future changes and the potential for "change collisions". In the next few paragraphs, we review each of these points in more detail.

Request For Change: Changes proposed for GENI originate from a number of sources, but principally from: 1) *research users*, who, through their work on the facility during its construction, either recognize the need for a change in technology, services, performance (or similar), or discover a new or better way to construct the facility by making the proposed changes; 2) *construction contractors*, who determine that an alternative to the original construction plan or design should be implemented in order to improve the facility, reduce its cost, or shorten the construction cycle; 3) *systems engineers*, who, during the course of facility deployment or testing, discover deficiencies in the facility and recognize that a change in a design or a particular component is required; 4) *project management or technical staff*, who recognize that the present course of the project will result in cost overruns, schedule delays, or similar unless a change is implemented. Whatever the source of a change request, a formal RFC must be submitted. The RFC will describe the change required, how it will benefit the project, the risks that it entails, what it will cost, the likely impact on project schedule and resources, etc.

The format for a RFC is well established and has been incorporated in many software applications for CCM. During the Preliminary Design period of planning, the GPO will select one of the commercial programs for CCM and create the design that will allow this program to be integrated into the overall PMCS for GENI.

Change Request Receipt and Logging: The responsibility for receipt and logging of RFCs falls to the Change Manager (CM). It is his responsibility to maintain a Change Register that is visible to the project community through the PMCS. The CM monitors and controls the progress of all changes within the project. In particular, he prioritizes changes (in collaboration with senior management), reviews RFCs for completeness, determines whether a formal analysis of the proposed change should be made should be needs made (e.g., for potential change collisions, for extraordinary impact on budget, schedule, or end-product performance or functionality, etc.). Finally, it is the responsibility of the CM to forward RFCs to the appointed Change Management Board after all preliminary work has been completed.

If it has been determined that a formal change analysis must be made for a proposed change, the CM (in collaboration with the PM) will appoint a Change Feasibility Committee (CFC) to carry out the analysis. The CFC will undertake an analysis for application and infrastructure-level changes, including hardware, software, and network modifications, to determine likely options for the proposed change – focusing on benefits to the project, risks associated with the change, potential costs, etc., - and document their recommendations. These recommendations will be made available to the entire GENI community through the PMCS.

Change Management Board (CMB): The CMB is the principal authority for evaluation and authorization of all RFCs. Its composition is described above. Its responsibility is to review all RFCs forwarded by the Change Manager; review all supporting documentation related to RFCs (e.g., the recommendations of the CFC; inputs from the community of facility users, etc.); and evaluate the potential for "change conflict" and recommend appropriate action to avoid such conflicts. Finally, the CMB authorizes the change request, recommends a time schedule for implementation of the change so that implementation causes the least interruption in the use of the facility during construction, and recommends a Change Implementation Team to carry out implementation of the approved change.

Change Implementation: Implementation of a change in the GENI Facility is carried out by a team appointed especially to implement a specific change or set of changes authorized by the CMB. It is the responsibility of the Change Implementation Team (CMT) to verify that a change has been authorized by the CMB before proceeding. The CMT then schedules the change (within the guidelines set by the CMB), validates that the proposed change is ready for deployment (e.g., by independent testing of changed hardware, software, applications, infrastructure, etc.), installs changes, retests to confirm that changes have been appropriately installed (including interoperability with other systems), receives "sign-off" on the change by the Change Manager and Project Manager, and requests closure of the change on the Change Register by the Change Manager.

Change Documentation: All changes made through the above processes will be documented and archived by the Systems Engineering function of the GPO. Appropriate changes will be made to design documents, drawings, schedules, budgets, etc., by the Systems Engineering function and made available to the project community. In addition, all documentation developed during the CCM process will be archived by Systems Engineering. The Change Register will be maintained by the Change Manager. All documentation will be available through the GENI Project Management Control System.