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Product Life-Cycle Modeling Utilizing SysML Modeling

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Abstract

SysML and UML are defined communication languages that engineers and related disciplines use to communicate the nature of engineering products. We often see UML and SysML used to describe large, physical entities, such as airplanes or space craft. Most often, systems engineers use SysML to decompose these large systems into subsystems. Each subsystem has defined requirements, defined roles and responsibilities, and definable interfaces. Each subsystem consists of electrical hardware, mechanical hardware, and computer software. These components are all hard engineering aspects.

Soft engineering aspects, such as program/project management, systems processes, and manufacturing processes, are seldom defined in any standard language. Most organizations use an array of flow charts, organization charts, network diagrams, and spread sheets to define engineering processes.

This paper presents how Sandia National Laboratories (SNL) uses SysML to define the design and development processes and procedures in the product realization process.

Author Biographies

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Georgia Artery is a Weapons Integration Engineer with Sandia National Laboratories. She has a Bachelors of Science in Mechanical Engineering from the University of New Mexico and a Masters of Business Administration from Webster University. She is currently pursuing a Masters degree in Systems Engineering at Stevens Institute of Technology. Georgia has worked at Sandia National Laboratories for 5 1/2 years with experience in Quality and Systems Engineering. Prior to Sandia, she worked at General Electric Aircraft Engines (GEAE) Division where she held multiple management and engineering roles in Quality, Manufacturing, and Process Engineering. In addition, she is a certified Six Sigma Black Belt from GE.

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Introduction

SysML and UML are languages used by engineers and the other related disciplines to communicate the design specification of engineering systems. They allow designers to define precisely how a system, and its constituent subsystems and components should behave in various environments and scenarios.

We often see large physical entities described using UML and SysML. System Engineers use SysML to decompose the large system into its component subsystems. They allocate requirements, roles, responsibilities, and interfaces to each subsystem. These attributes get satisfied by parts built under one of the engineering disciplines (generally, mechanical hardware, electrical hardware, and computer software). The disciplines are often referred to as the hard engineering disciplines.

What is seldom seen is the same rigor of modeling applied to the “less hard” engineering disciplines of systems engineering. Program Integration, System Integration, and Product Realization are examples of stakeholder departments that perform processes as part of the overall project. If a step is missed, the overall project may be affected with potentially catastrophic results.

Historically, engineering processes have been built using flow charts, organization charts, network diagrams, and spread sheets. These methods do not provide an easy way to confirm the process correctness and completeness. In addition, each group defines artifacts differently.

Engineering processes have requirements, roles, responsibilities, and interfaces, just like the hard engineering disciplines. Therefore, “process systems” can be modeled using SysML. Once modeled, they can be simulated to verify correctness, completeness, and consistency.

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This paper demonstrates how SNL is modeling its product realization process called Integrated Phase Gate (IPG) Process using SysML. Building this model required inputs from several groups of differing domains. Each domain has its own language which would have made this project far more difficult without SysML. SysML provided the standard means of communication to enable the participants to translate their domain-specific terms into common terms used in the overall model. Note that this model is a base model or standard model. Specific projects may derive process attributes from this model to meet project-specific requirements.

The basic premise of the model is that every process phase can be modeled as a block composed of tasks. Tasks can also be modeled as blocks that can be decomposed further to assign sub-tasks to individual actors. Actors represent the people who perform the tasks (e.g., Project Manager, Systems Engineer) and the other stakeholders (e.g., customer, manufacturing).

Tasks “have” documents, where documents represent an artifact that is created or modified by a task. Documents may be paper documents (e.g., SRS, SDD, and policy statements), system models, or hardware components.

Background

SNL develops science-based technologies that support our national security. One of Sandia’s key missions is to ensure the Nuclear Weapon stockpile is safe, secure, reliable, and can support the United States’ deterrence policy. The Weapons Program Integration department at SNL provides technical and administrative integration support to Systems, Subsystem, and Component project staff for the Nuclear Weapons Complex (NWC).

Over the past five decades, the Complex has been using legacy product realization processes that have often resulted in programs running over budget, cost, and schedule. The Nuclear Weapons Enterprise model has four key elements in the weapon life cycle; Conduct Research, Design and Develop, Produce, and Maintain & Sustain. Therefore, the Weapons Integration department was tasked to improve and standardize the Design and Develop processes. The objectives for the project were to:

1. Create an improved and standardize product realization process for all NW projects with a graded approach.
2. Create a checklist that will define the activities required at each phase in the product life-cycle along with inputs, outputs, and responsibilities for all engineering and support functions.

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From management's perspective, they want to have a well-defined and integrated process that any engineer, both new and established, can use to identify the tasks within each phase, understand those tasks they are responsible for completing, identify others involved in each task, and the deliverables required to complete each phase.

A project team was identified and the team conducted a week long meeting to develop the new process. The process was documented and socialized within the Weapons Engineering and Product Realization Division. Upon review of the comments and feedback, it was not clear to stakeholders what the connections and relationships of the users, tasks, and the inputs/outputs were to reviews or gates. One of the underlying objectives was to embed Systems Engineering principles in the process. Therefore, the team proceeded with a parallel approach to create the process architecture using IDEF0 diagrams and then built the process model in SysML.

Problem Statement

The Systems Integration Department at SNL was charged with reviewing and updating the product realization process and procedures for a business unit within Sandia. The goal is to define a standardized process for all weapon design and development work. The process must include all the high level processes, phase tasks, and the criteria needed for each gate review. The process should follow good project management practices and systems engineering principles but allow for the security customizations that the nuclear weapons industry requires.

Solution Domain

The basic premise of the model is that every process phase can be modeled as a block composed of tasks. Tasks can also be modeled as blocks (which can be decomposed further when necessary). Tasks "have" artifacts, where artifacts represent the items that are created or modified by the task. Artifacts may be paper documents (e.g., SRS, SDD, and policy statements), system models, or hardware components. Actors represent the people who perform the tasks (e.g., Program Integration Engineer, Systems Engineer, and Requirements Engineer) and other stakeholders (e.g., customer, manufacturing). The model will be used to understand the process flow and the connectivity of the tasks.

Modeling Approach and Results

Functional Model

There were two approaches taken to look at the Behavioral models of this process, IDEF0 diagrams and use case diagrams. An IDEF0 diagram was created and underscores how important it is to take a system engineering approach to process development by the use of modeling. It was observed in the first pass of the functional decomposition that the architecture lacked cohesion and leveling. In order to build the SysML model, it was important to understand the connectivity for all the elements. The IDEF0 diagram was used to refine the tasks, inputs, and outputs for each phase and clarify the relationships between tasks and gate outputs. Once the IDEF0 diagrams were completed, the SysML model was created.

SysML Model

The objective of the SysML model is to build the behaviorial and structural elements of the process which are then joined by the use of executable activity diagrams for the use cases and statechart behavior for the process artifacts. In this approach, the model starts by representing the hierarchy and relationships of the controlling documents and derived process requirements which was the driver for the project team to improve the product realization process. The team steps through various levels of the process describing the relationships of the stakeholders, process structure and elements, and all artifacts created in the process. At the next level of the model and for the purpose of illustration in this paper, one use case was selected and then drilled down to the next level in the form of an activity diagram. The activity diagram is then tied back to the structure via a statechart for the affected artifact. A complete look at the process is show in the following diagrams.

Requirements

The motivation for this project was communicated by NNSA through a Memo of Understanding (MOU) describing an agreement between NNSA and their contractor organizations to improve the product realization process. In addition, it is important to understand the hierarchy of all the business requirements and which stakeholder owns each requirement. The high level requirement hierarchy, as shown in figure 1, represents how requirements from NNSA are driven down through a Development and Production Manual (D&P Manual) into Technical Business Practices for the NWC, and then into procedures for which Sandia conducts its operations.

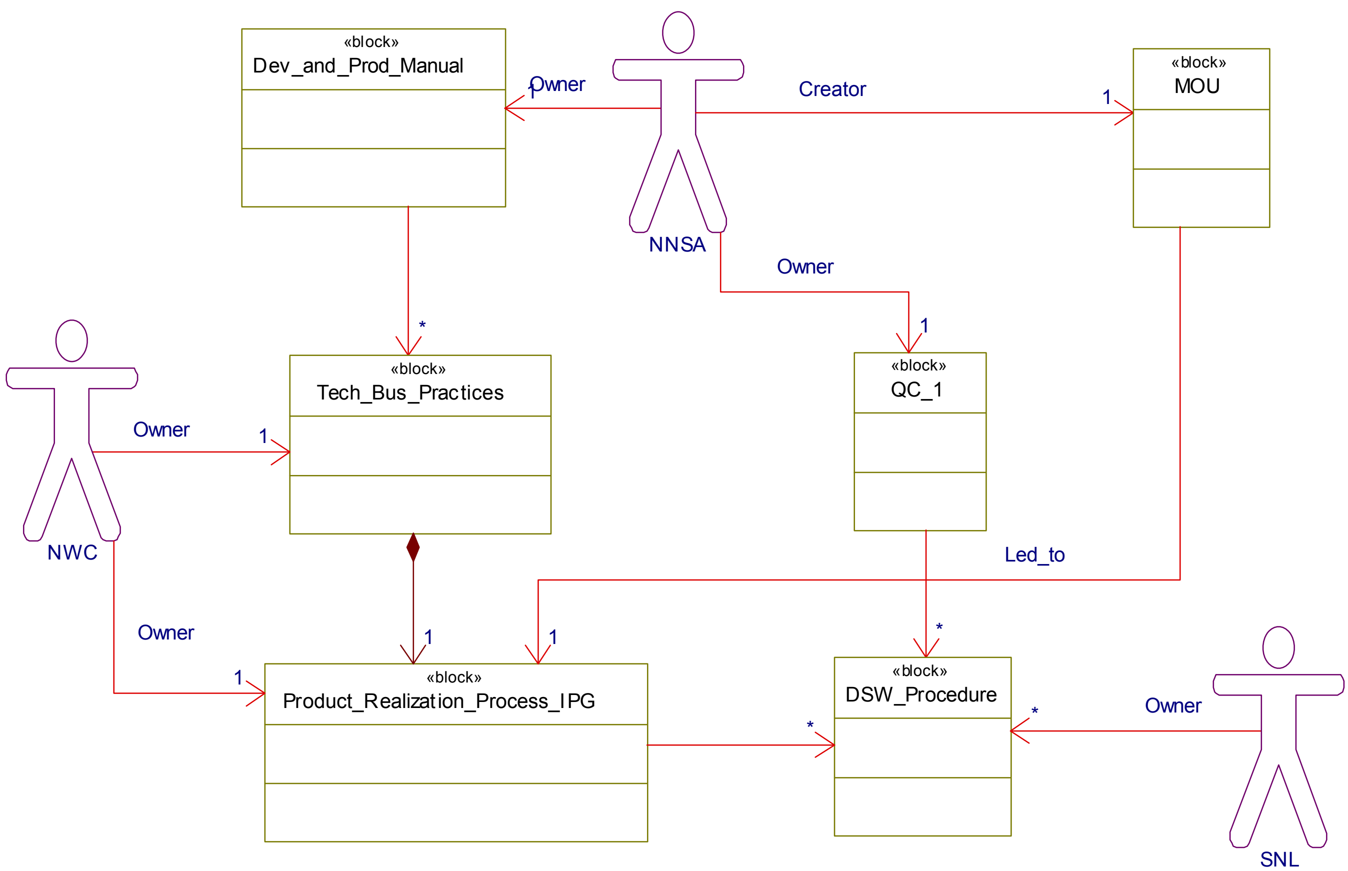

Figure 1: Controlling Documents & Project Drivers

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Use Cases for Top Level Process

At the top level, six phases of the product realization process were created which begin by eliciting stakeholder requirements and continues through the design/development, verification/validation, and delivery of first production units. The product architecture follows the Vee Model of systems engineering where the process is applied at multiple levels, including system, subsystem, and component levels. These phases were created into the model as use cases and associations were identified to link the actors to the respective phases that require their participation (figure 2).

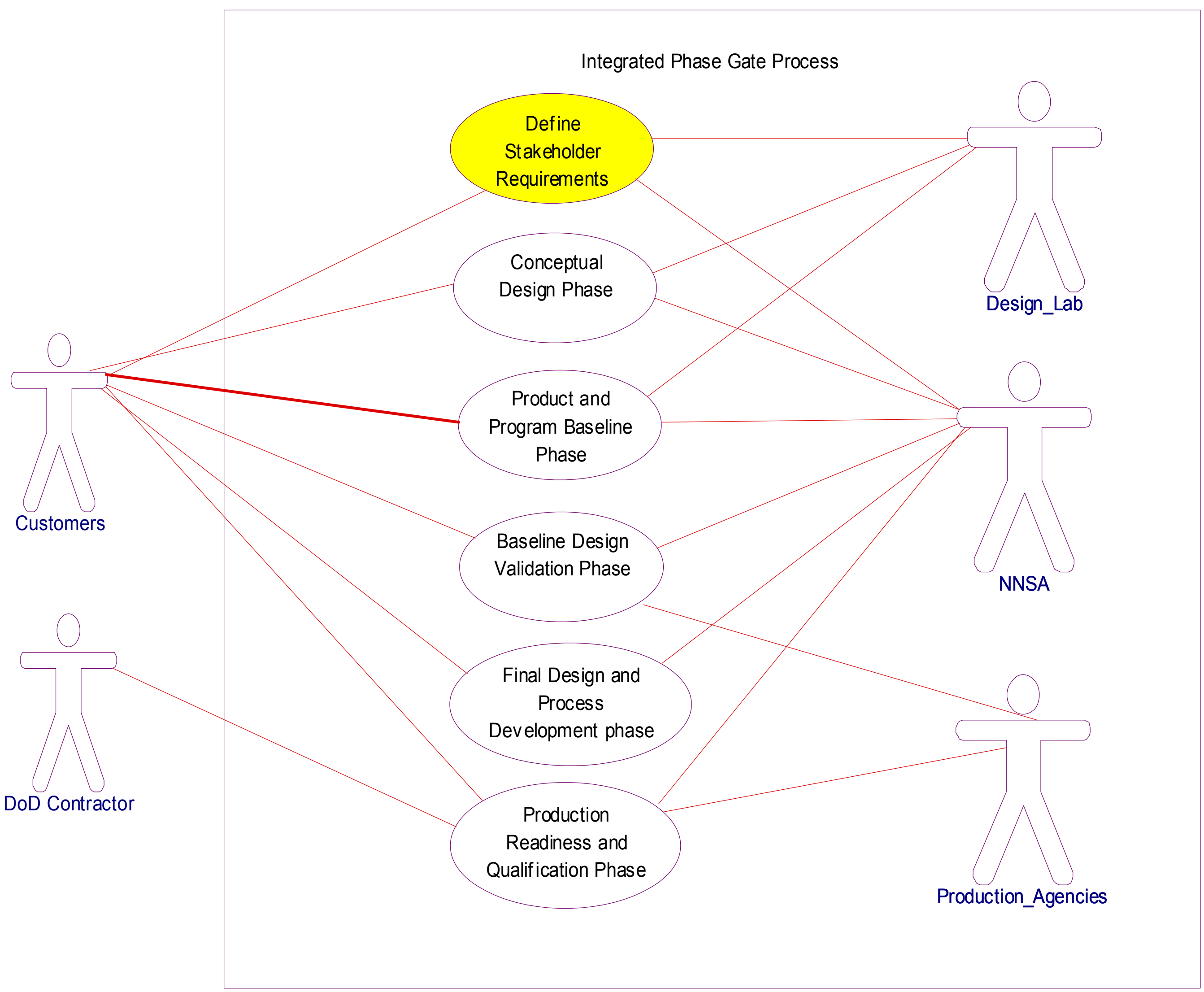

Figure 2: Top Level Process

Block Relationships

The key elements of the process are represented by the six phases decribed above. At the end of each phase is a gate review. The gate review has specific inputs that are needed to enter the gate and agreed upon outputs to proceed to the next phase. Each phase requires a specific list of tasks to meet the deliverables of each gate. A basic structure of these elements and their relationships are shown in figure 3.

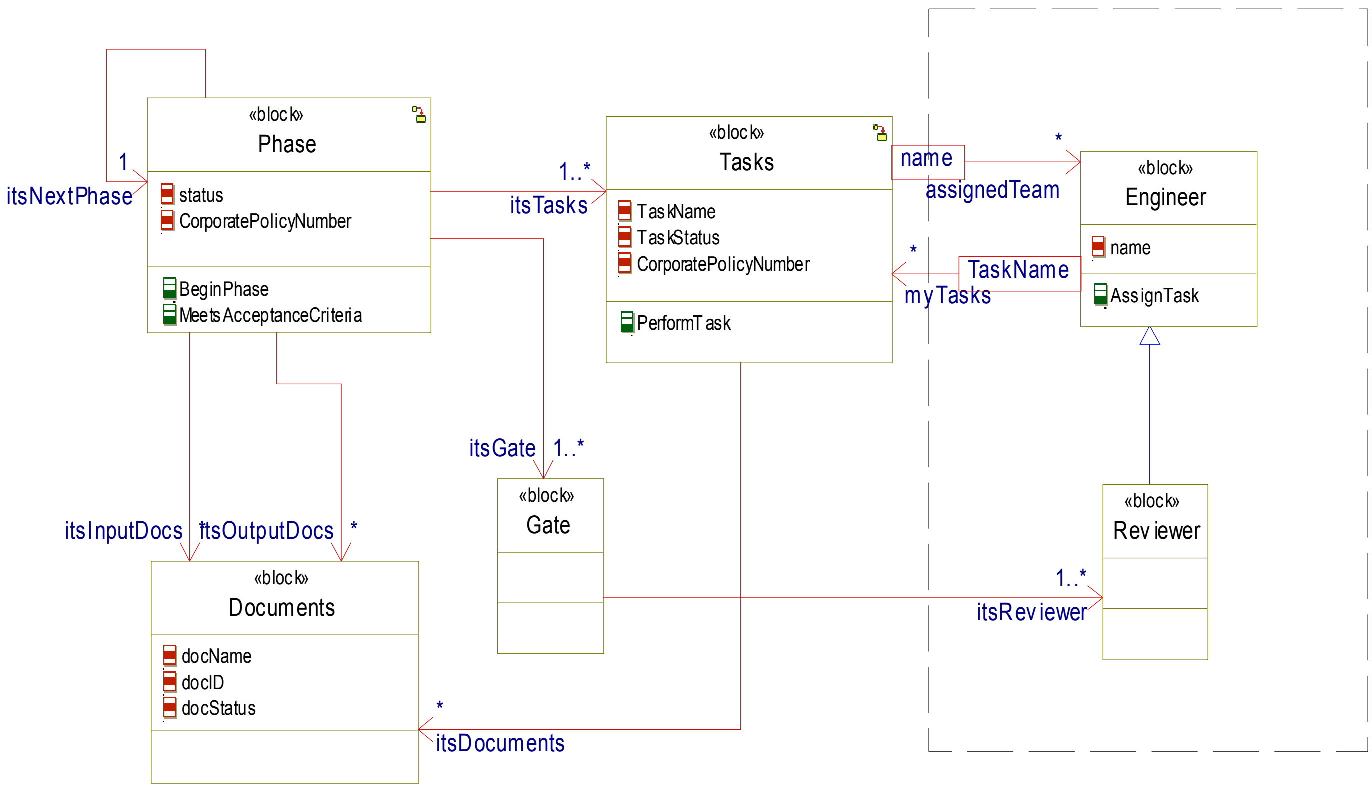

Figure 3: Block Relationships

Stakeholder Relationships

The key stakeholders in the process are depicted as actors in figure 4. The stakeholders are represented by internal and external stakeholders. Stakeholders are the individuals or entities of the system that will either actively interact with the process (internal) or can influence the success of the process (external). The actors are defined at each level of the process in order to show their relationships within the entire model.

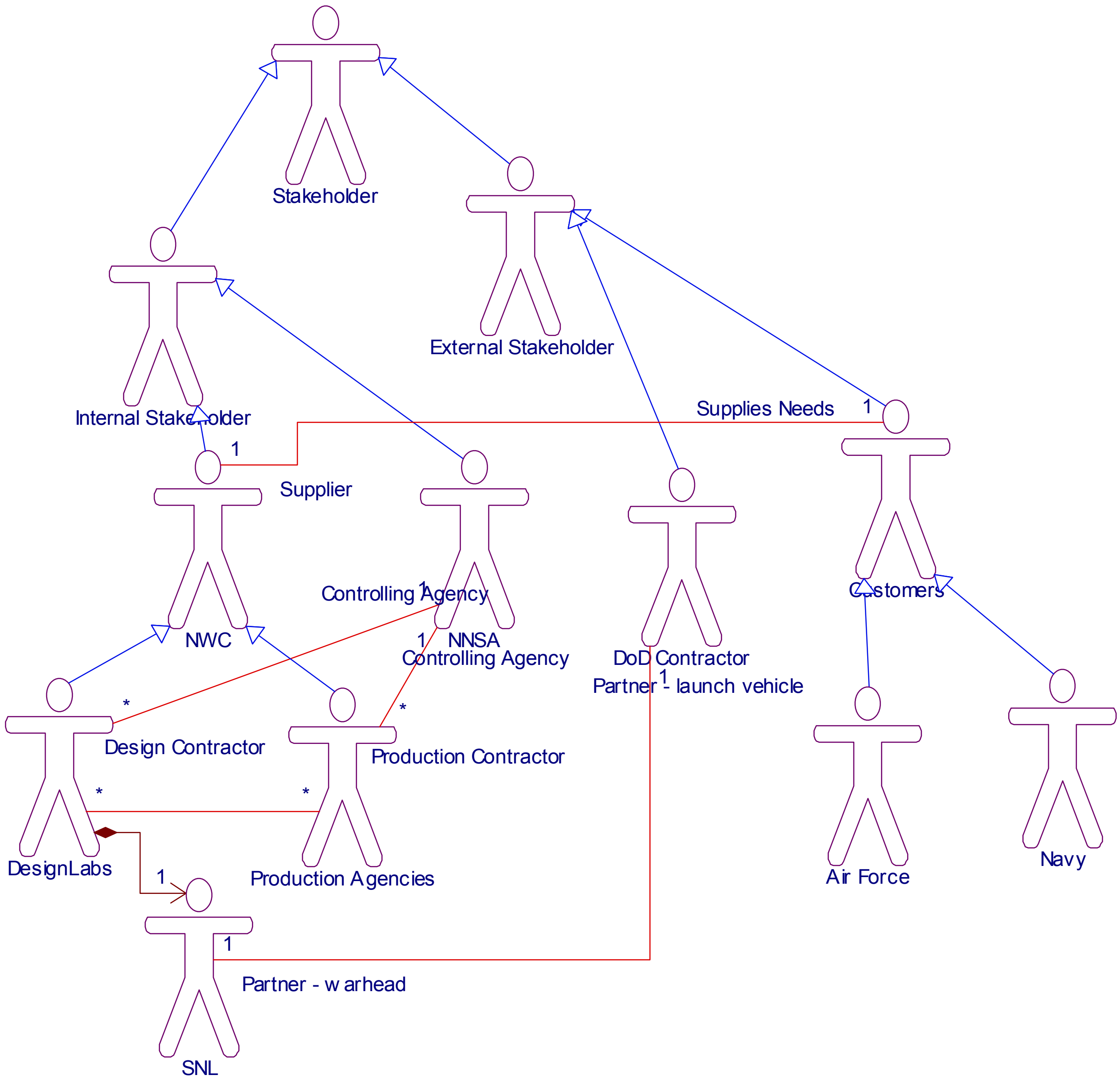

Figure 4: Stakeholder Relationships

High Level Process Structure

The structure of the Integrated Phase Gate process contains Stakeholders, Process artifacts, and Products. Elements of these can be further described; Stakeholders are composed of internal and external, Process artifacts are composed of product and program elements, and Products are composed of subsystem/components and support products. At the next level down, Products are composed of requirements, system design documents, and product plans. The high level structure is shown in figure 5.

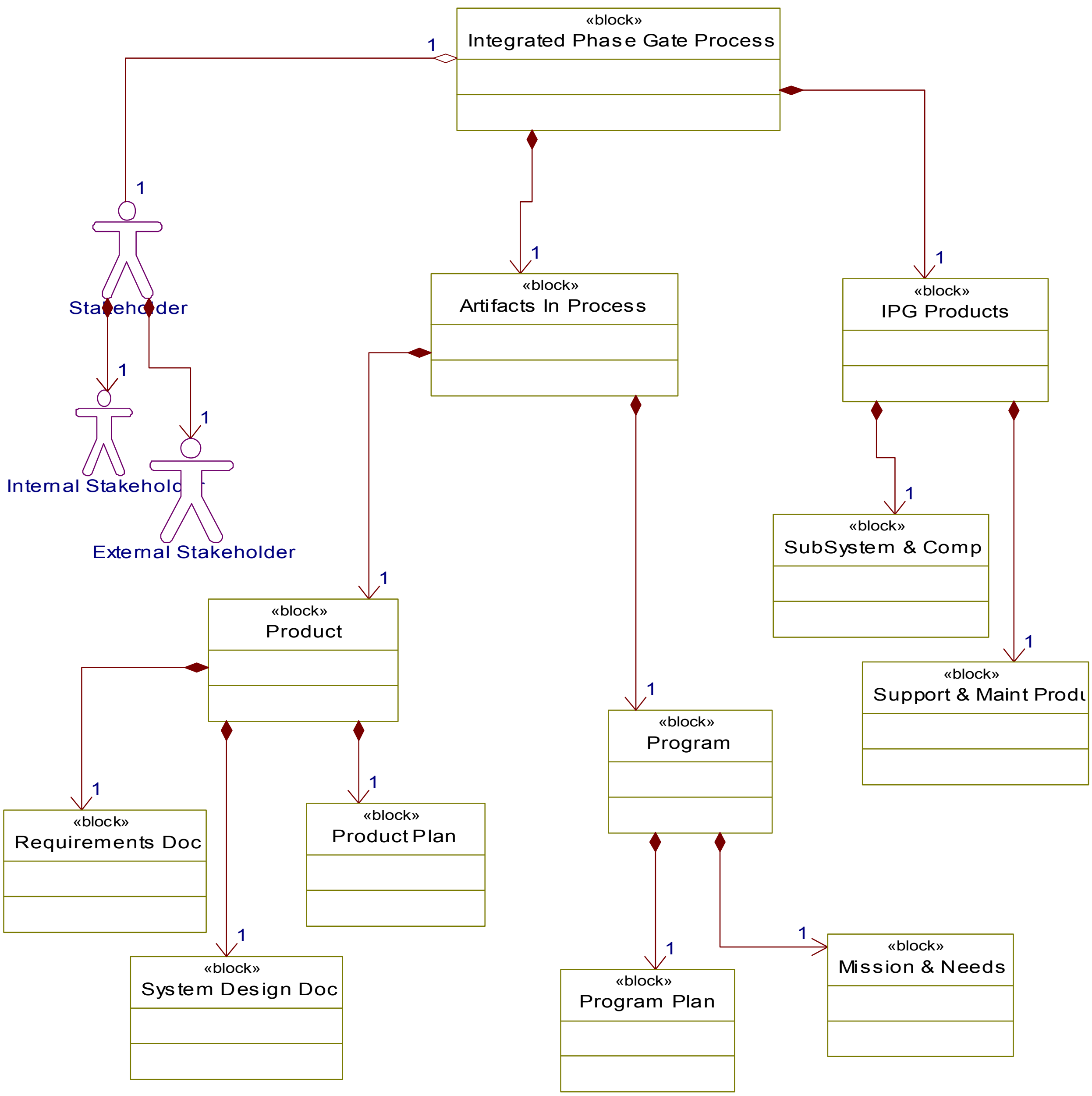

Figure 5: High Level Structure

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Artifacts of Process

The artifacts for the product realization process are defined in the block definition figure below. From this point the executable model is developed using statecharts. To illustrate, the highlighted “Source_Req” will be expanded and explained in the balance of the paper.

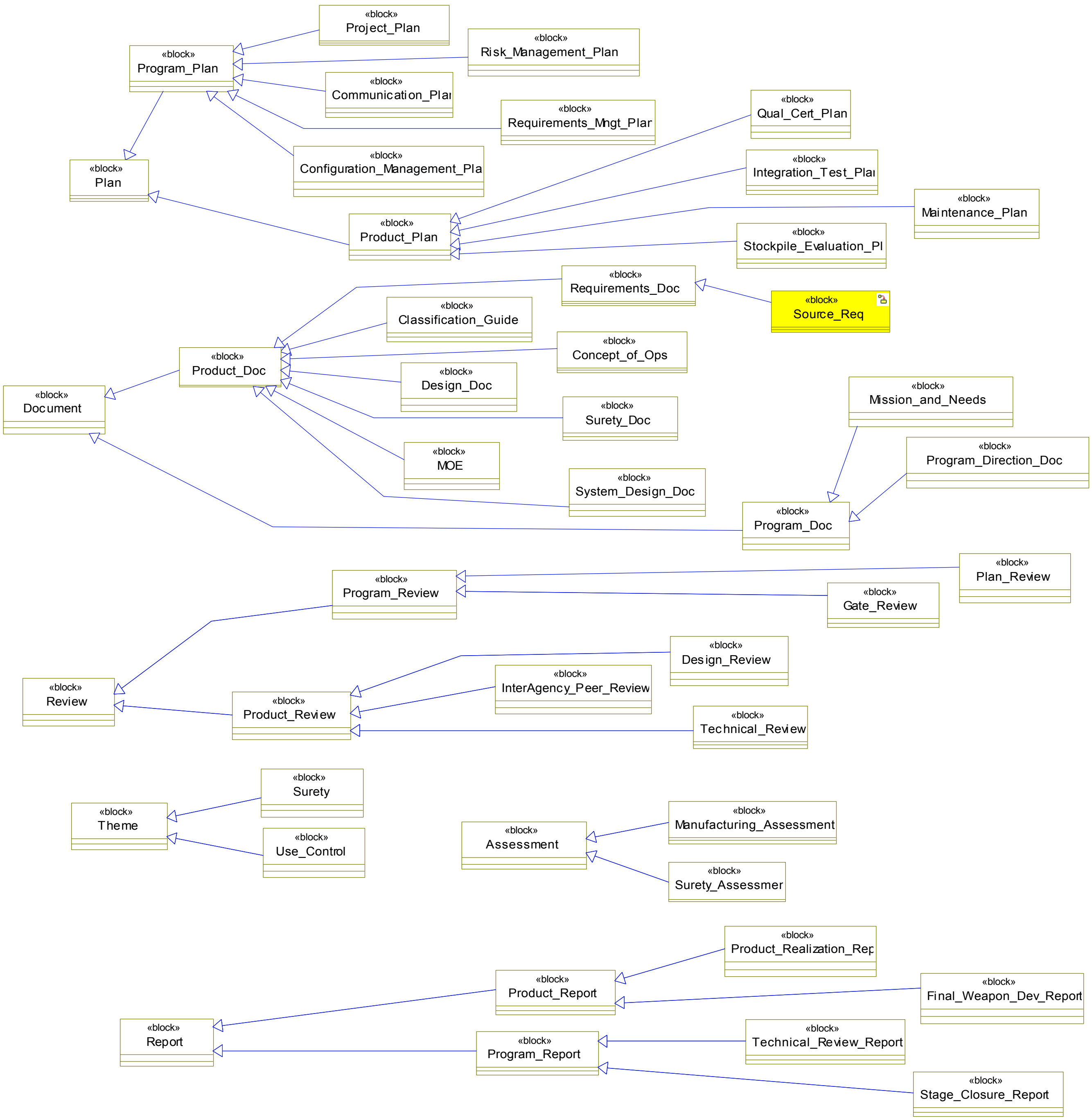

Figure 6: Artifacts of Process

Use Case Diagram for Phase A

In the next level, the use case for the first phase of the process was created. Each of the tasks in the phase is represented in figure 7. The use case highlighted will be further described in an activity diagram. The activity diagram specifies the tasks to complete the use case and modify the artifacts for that use case via the statechart for the artifact, which forms the bridge between the behavioral and structural elements of the model.

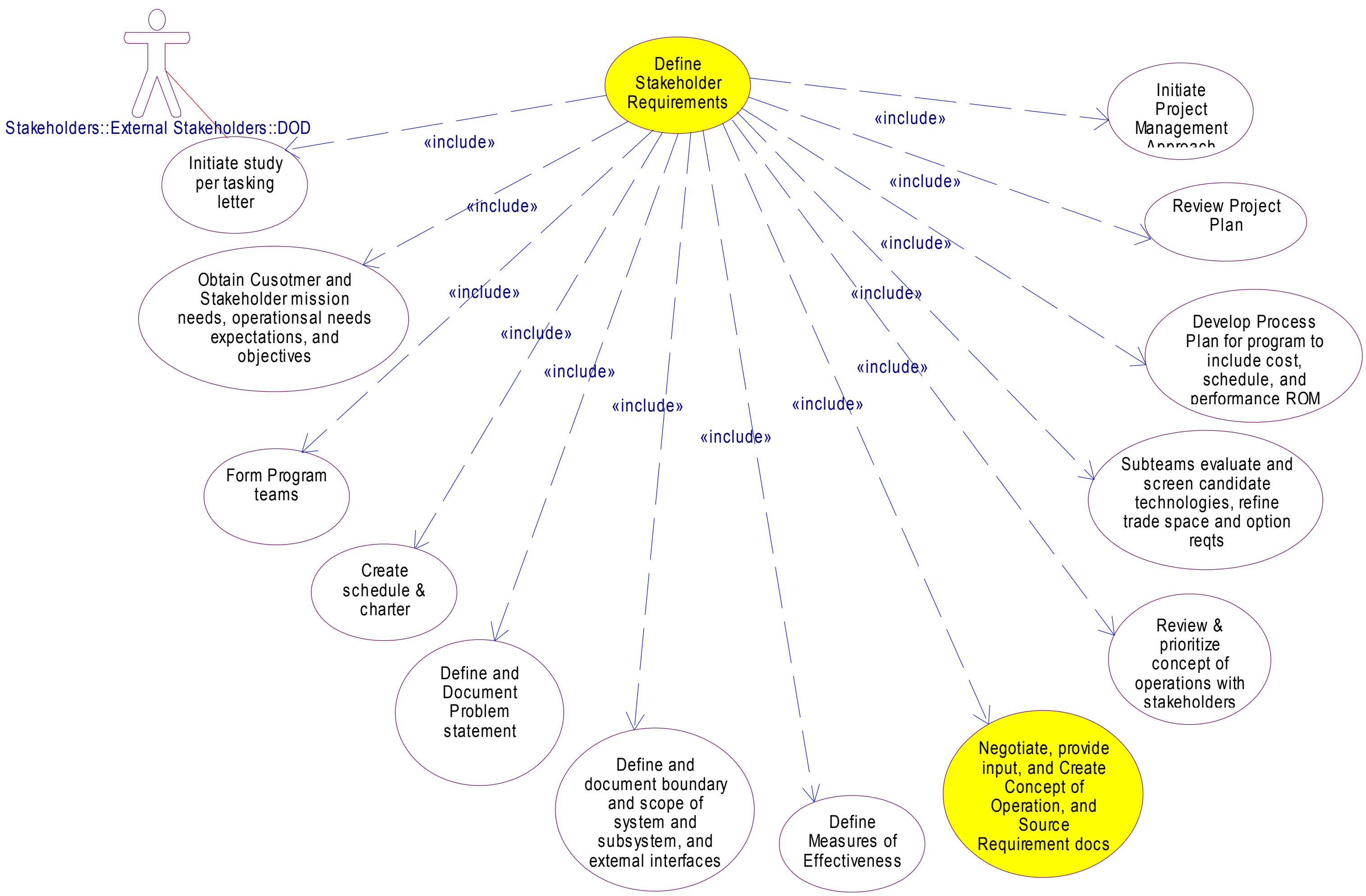

Figure 7: Use Case of Phase A

Source Requirements

The system block, “Create_Source_Reqmts”, is the analogue to the highlighted use case. For model completeness, the stakeholders involved in this specific process (use case) are included in figure 8. Also included is the block, “Create_Source_Rqmts”, which is the artifact that is modified by this use case.

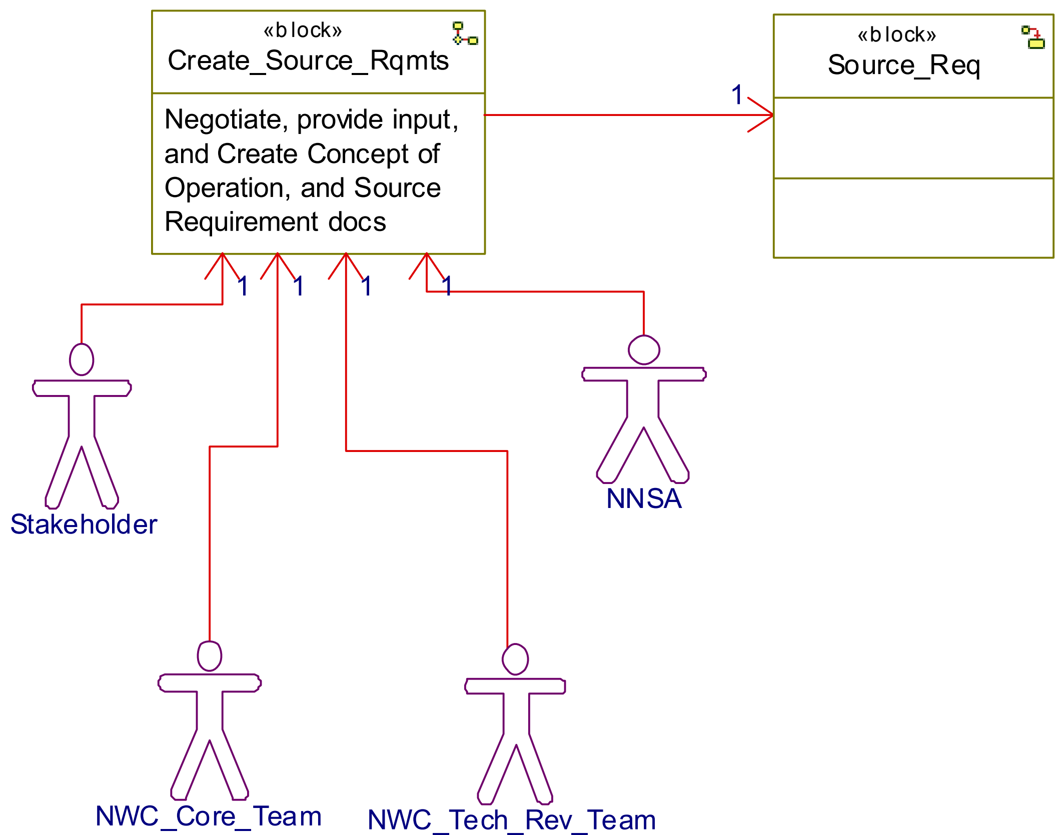

Figure 8: Source Requirements

The “Create Source Requirements” block definition diagram is implemented with an internal block diagram of the same name where the blocks have been converted to instantiated parts and the associations to corresponding links. The “Create_Source_Rqmts” process is implemented with an activity diagram that generates events which drive state changes in the “Source_Req” statechart. As the process progresses through its activities, the state of the artifact, “Source_Req”, goes from “undefined” through “validated” (see figures 10 & 11).

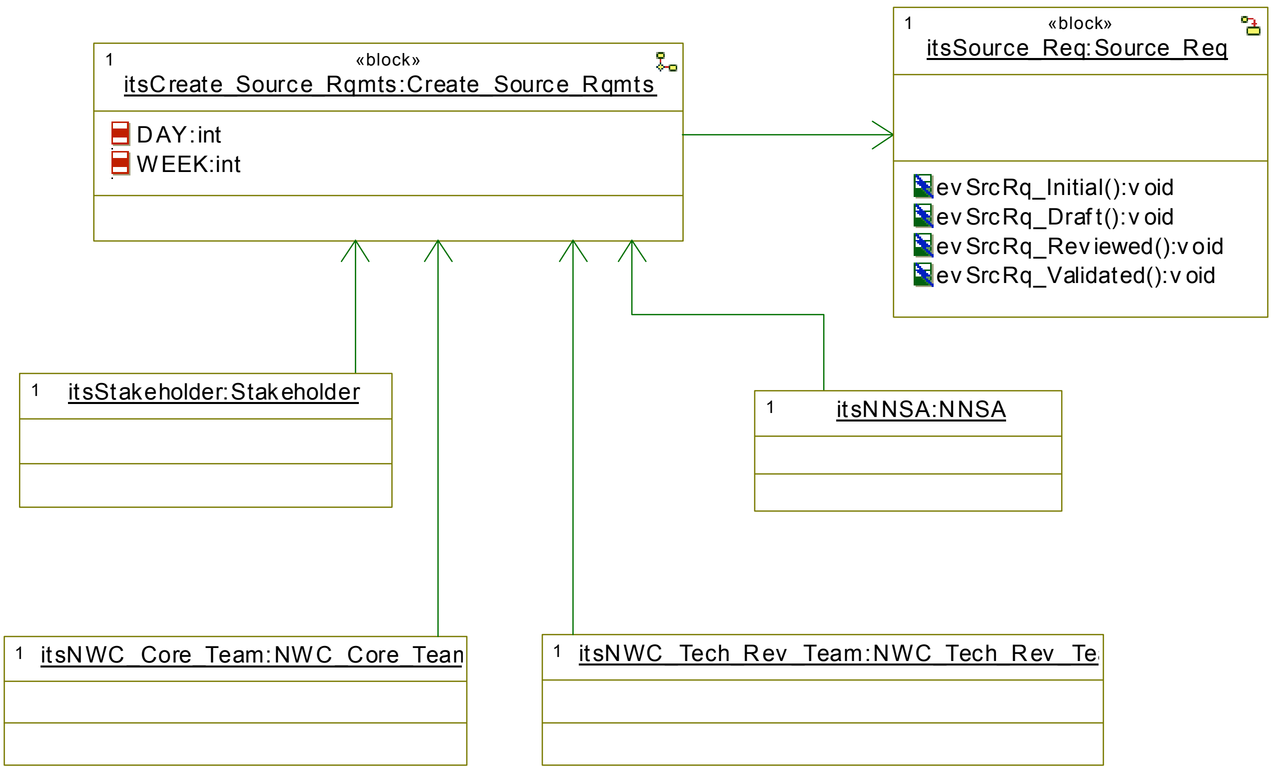

Figure 9: Internal Block Diagram of Source Requirements

The “Create_Source_Rqmts” process is implemented with an activity diagram. The swim lanes represent the stakeholders from the block definition diagram where events are generated and drive the state changes in the “Source_Req” statechart (figure 11).

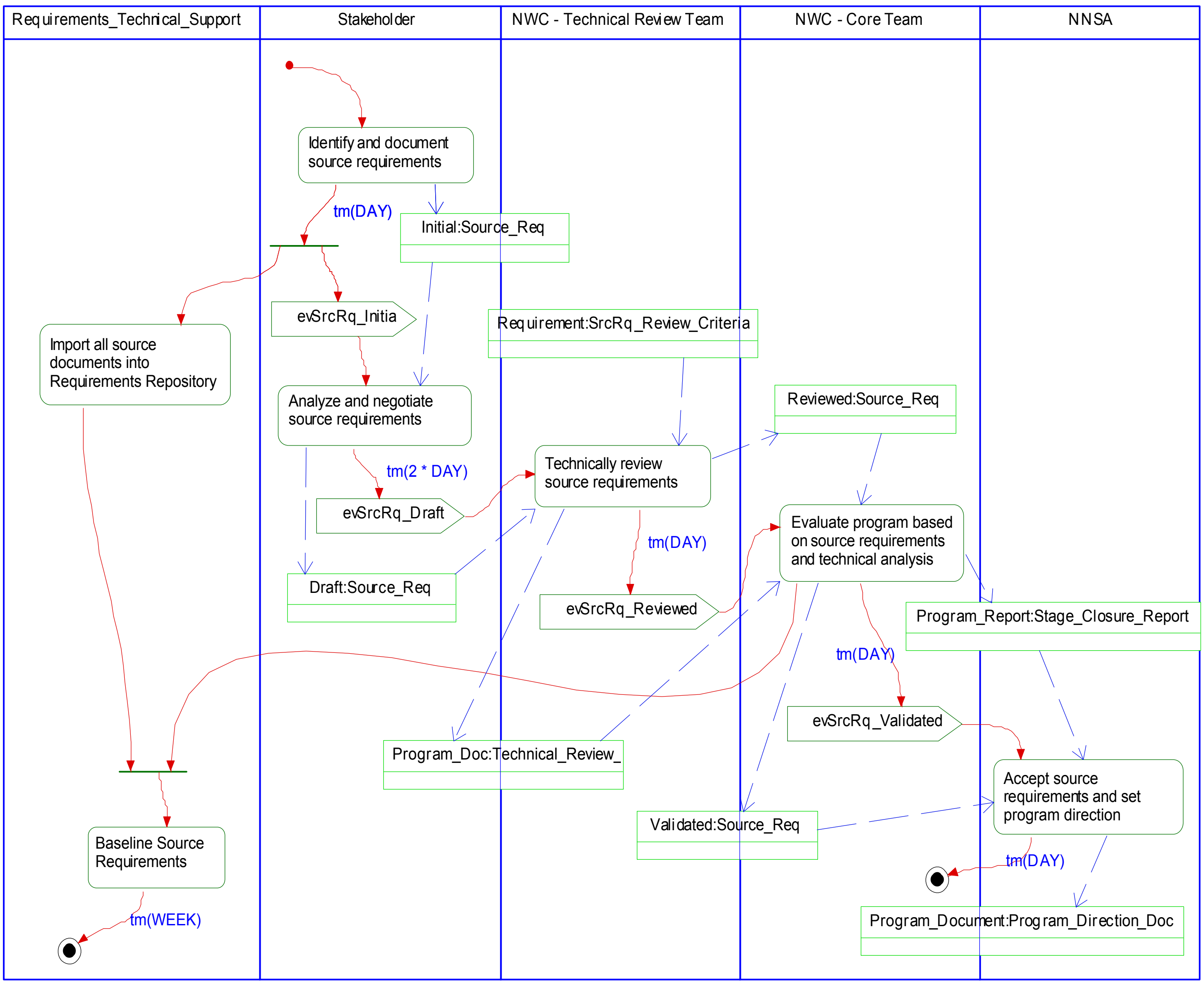

Figure 10: Activity Diagram for Source Requirements

The artifact “Source_Req” is represented by a statechart that illustrates the transformation of the artifact from “undefined” through “validated”. The state transitions are driven by events that originate in the process activity diagram (see figure 10). The state chart ties back to the “Source_Requirement” artifact highlighted in figure 6.

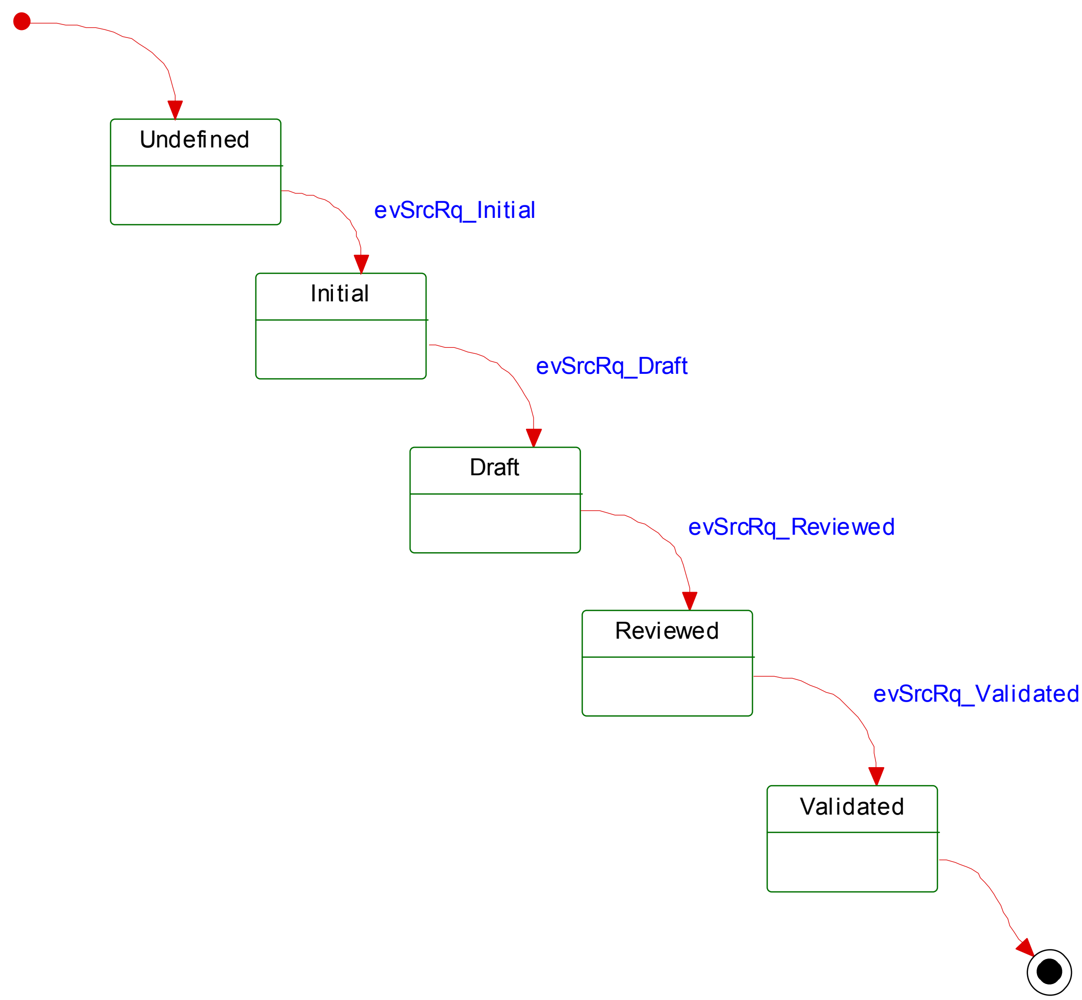

Figure 11: Statechart for Source Requirements

Summary

The modeling results and observations, both behavioral and structural, will be presented to the Product Realization team as a standard by which to develop the processes used on projects. The initial functional modeling provides a structural approach with the identification of gaps and connectivity of the process elements. The SysML modeling effort will specify the flow and intent of the process that is needed for completeness. This will eliminate inefficiencies and create an enhanced concurrent engineering process to better manage the cost and schedule, and maintain performance of future programs.

It is clear that the static modeling effort has provided benefit in completeness and consistency, thereby reducing the ambiguity that teams must muddle through in order to execute projects. It is still unclear the cost/benefit trade-off in the dynamic model for the entire IPG. If all artifacts and the states and events are completely defined and simulated, there is a large investment required. Sandia will simulate pieces of the model at the highest gate level transitions but detailed transitions may not provide the benefit given the effort.

In the future, this model is still being tested on key elements of the process. This process is very complex in nature, therefore the team will continue to build on key artifacts and elements in all phases of the process. There is an opportunity to pilot the executable on specific elements of the process on an upcoming development program at Sandia National Laboratories.

Resources

http://www.sandia.gov/about/index.html

"Fundamentals of Systems Engineering: system Operational Effectiveness and Life Cycle Analysis", Stevens Institute of Technology, SDOE 625 Course material.