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# Using Systems Engineering to Design and Evaluate a Transparent and Accessible Vaccine Appointment and Delivery System

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Critical Infrastructure Protection and Recovery (CIPR) Working Group

www.incose.org/symp2022

# CIPR Working Group

- Apply systems engineering to critical infrastructure issues
- Other active projects:
  - **Resilient Hospital Reference Model** – John Juhasz
  - **DHS SysML and other models** related to US critical infrastructure (in concert with Idaho National Laboratories) – Tony Adebonojo, Dan Eisenberg, Ryan Hruska
  - **Cybersecurity of Industrial Control Systems** (in concert with IEEE, ISA and other professional societies and organizations) – Aleksandra Scalco, John Juhasz

# Team Members

- David Alldredge, PE, ESEP – Chesapeake Chapter, Retired
- Douglas Bodner, PhD, PE – Atlanta Chapter, Georgia Tech
- Stephen J. Sutton, PE-Retired, ESEP – Chesapeake Chapter

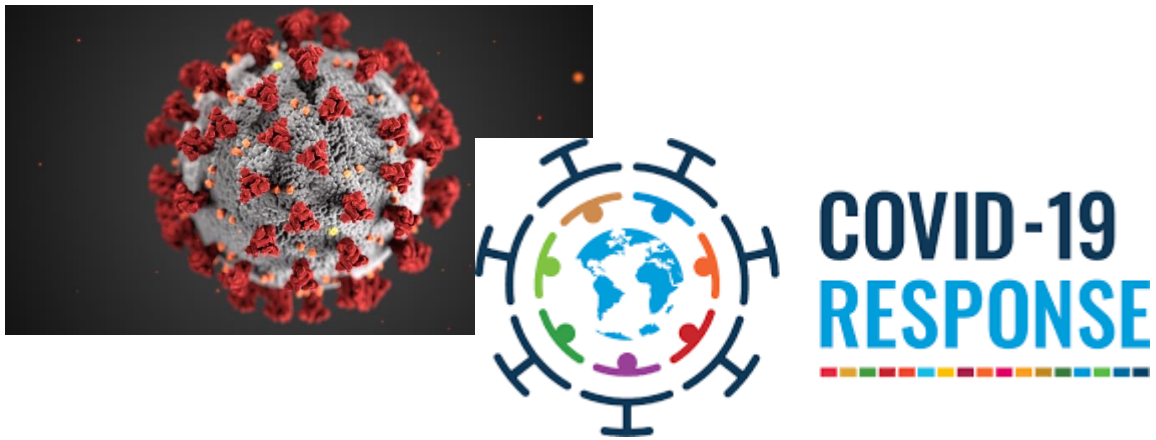
# Thank You

- Dessault Systemes for the use of their Cameo Enterprise Architecture MBSE tool

# Agenda

- Motivation
- Operational Needs
- MOEs
- System Design Through SysML Artifacts
- Simulation
- Moving Forward

# Motivation



- Worldwide threat
- Worldwide response
- Lockdowns
- Fear
- Hope – Vaccines
- Anxiety – How and when to get jab?

Images from internet

# Motivation – Why Anxiety?

- January 2021 – Appointment frustration
- It's who you know
- How should a vaccine delivery system work?
- Application for systems thinking and systems engineering

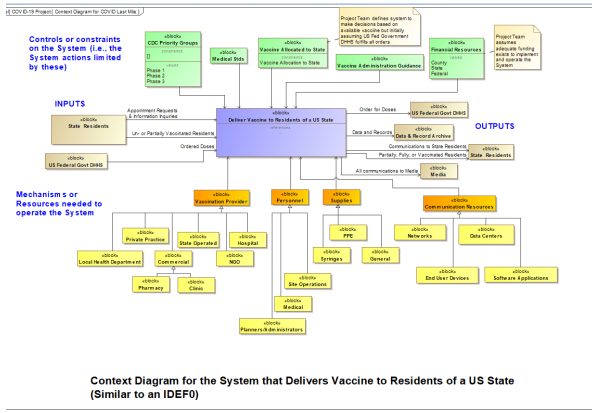
# Operational Needs

- Available to all who qualify; no discrimination
- Single point of entry
- Multiple ways to enter the system
- Ability to validate eligibility
- All available appointments presented
- Choice of vaccine available
- Avoid multiple bookings and gaming the system
- Ensure cybersecurity and integrity of data presented to, held by, and transmitted outside of the system
- Operational 24/7

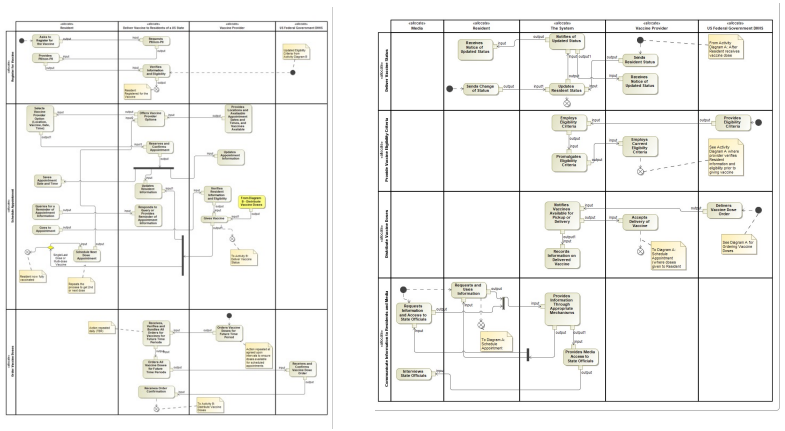
# MOEs (TBR)

- System Capacity
- Number of Successful Vaccinations vs. Number of Appointments Made
- Time Between Scheduling and Receiving the First (or only dose) or a Booster
- Variation in Time to Schedule/Receive Second Dose (nominal 3- or 4-weeks vaccine dependent)

# Implementation Independent System Definition

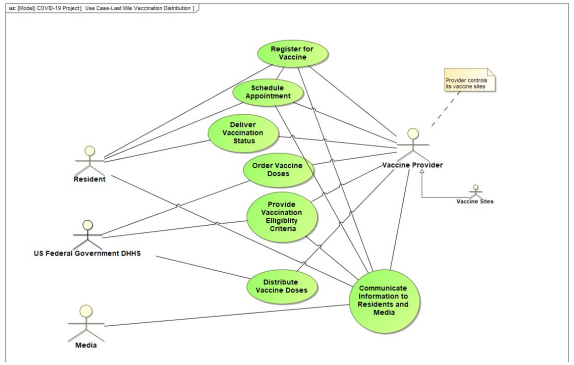



BDD for a Context Diagram

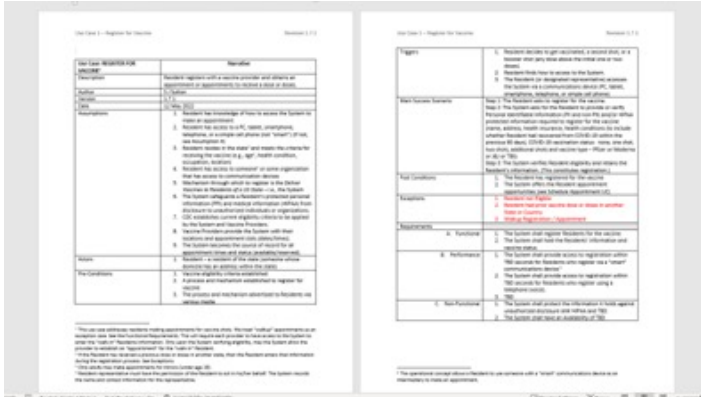


Activity Diagram

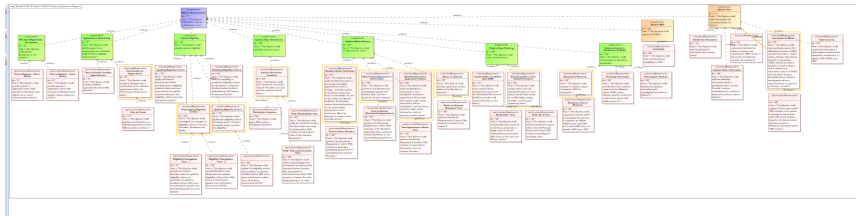
SysML Artifacts to Describe Desired System Operation that Satisfies the Operational Needs




Use Case Diagram



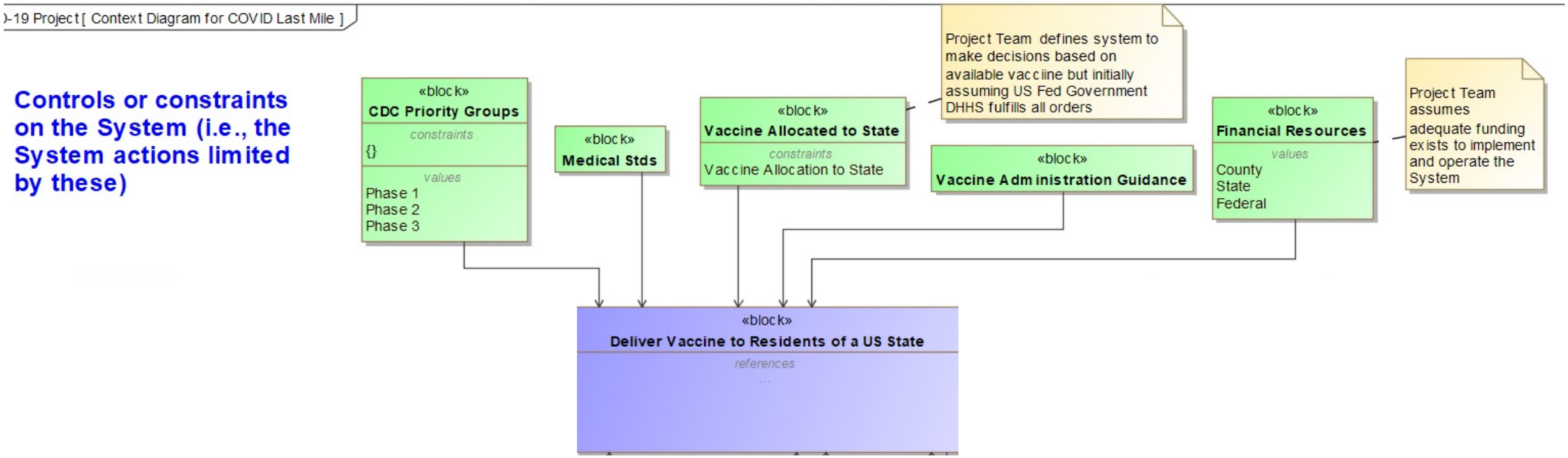
Narratives – “Specification”



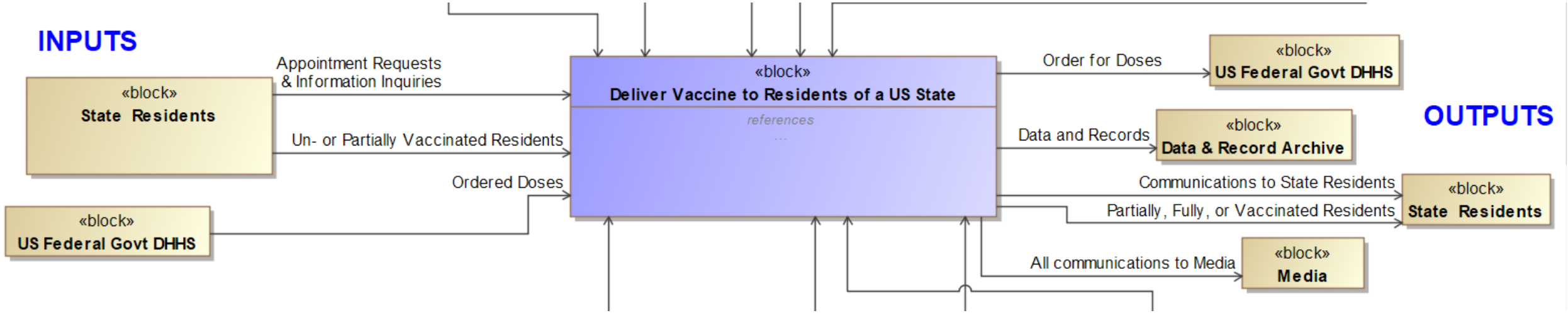
Requirements Diagram

# Defining the System: External Relationships (1)

**Controls or constraints on the System (i.e., the System actions limited by these)**

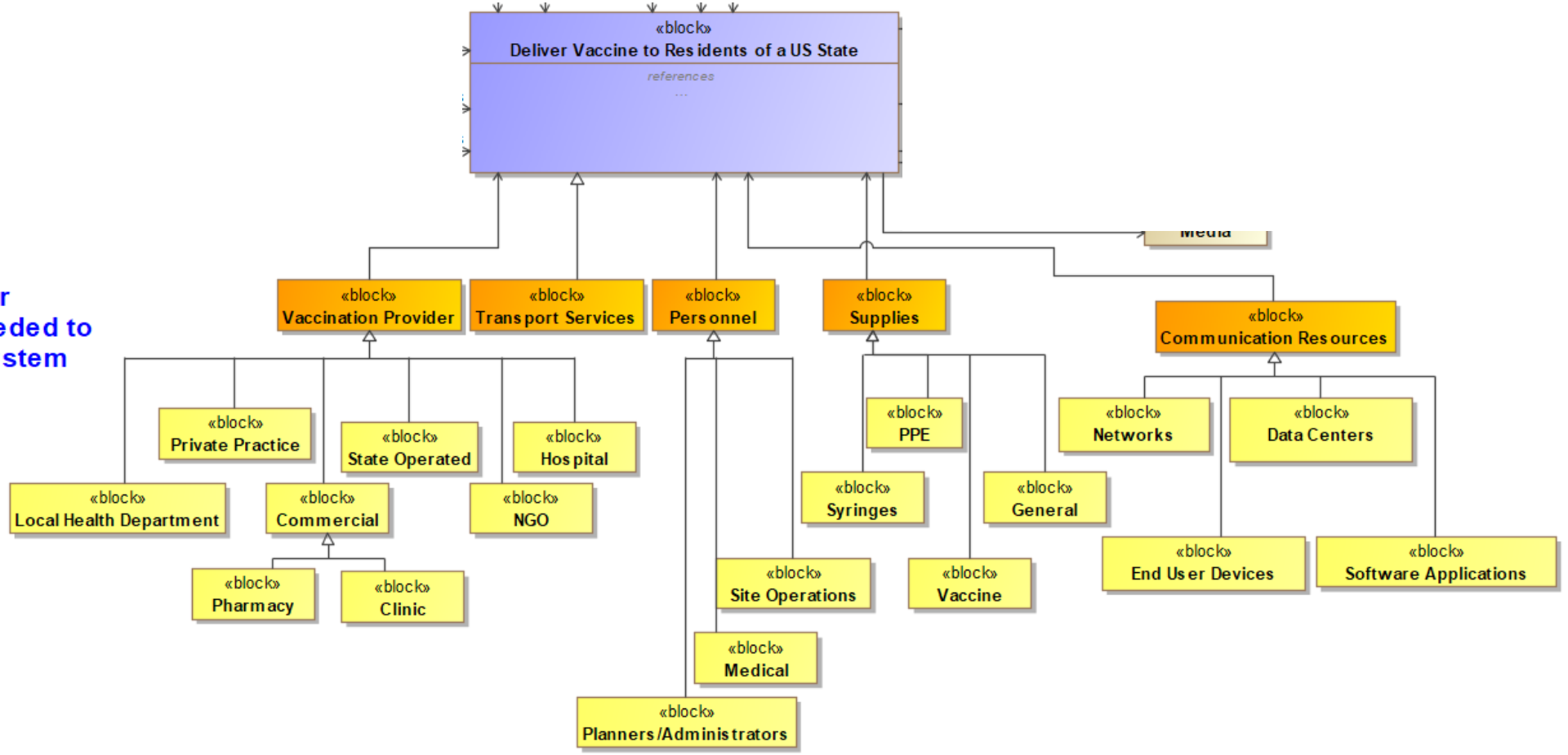


# Defining the System: External Relationships (2)

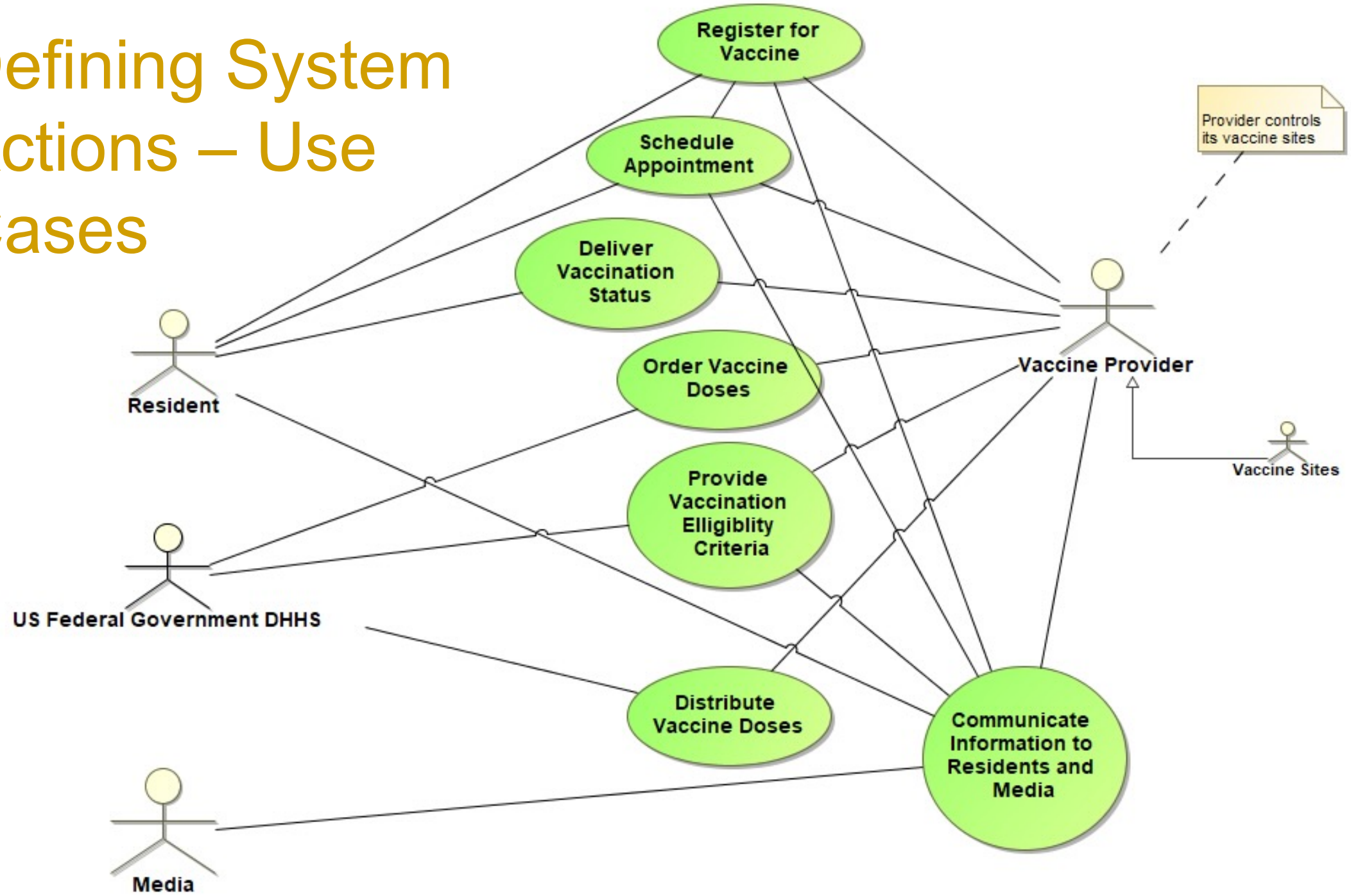


# Defining the System: External Relationships (3)

**Mechanisms or Resources needed to operate the System**



# Defining System Actions – Use Cases



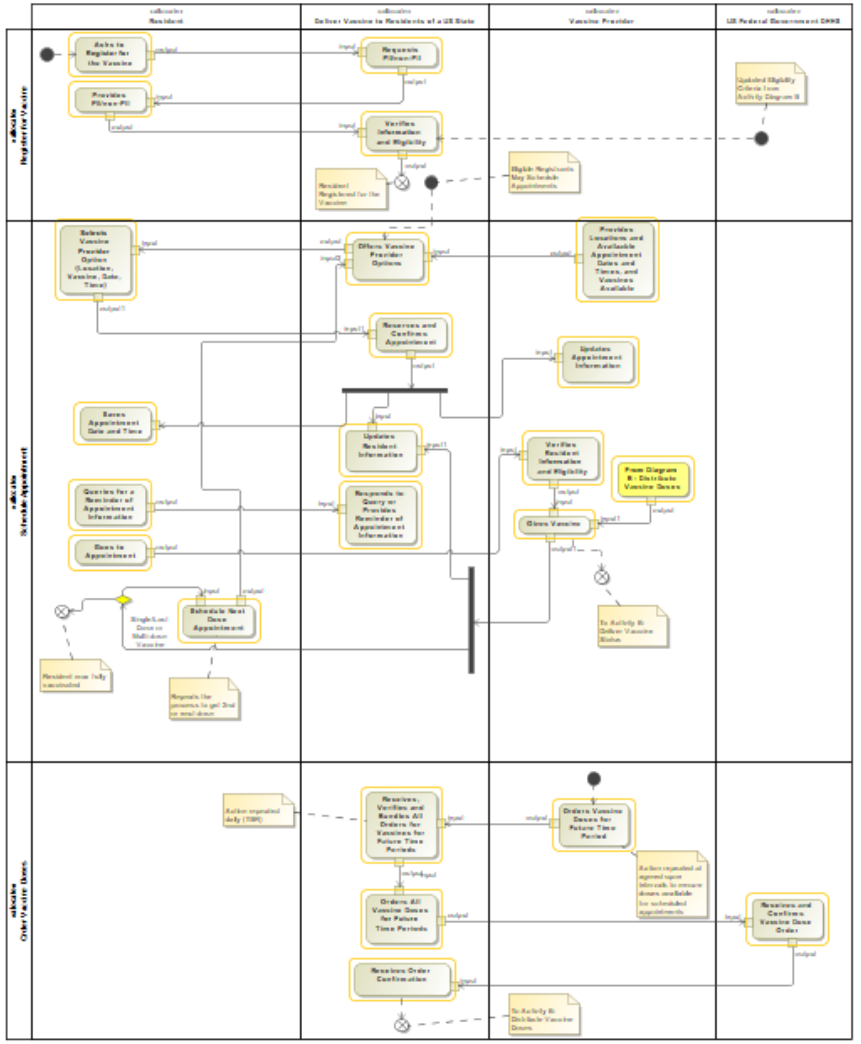
# Use Case Narrative (“Specification”)

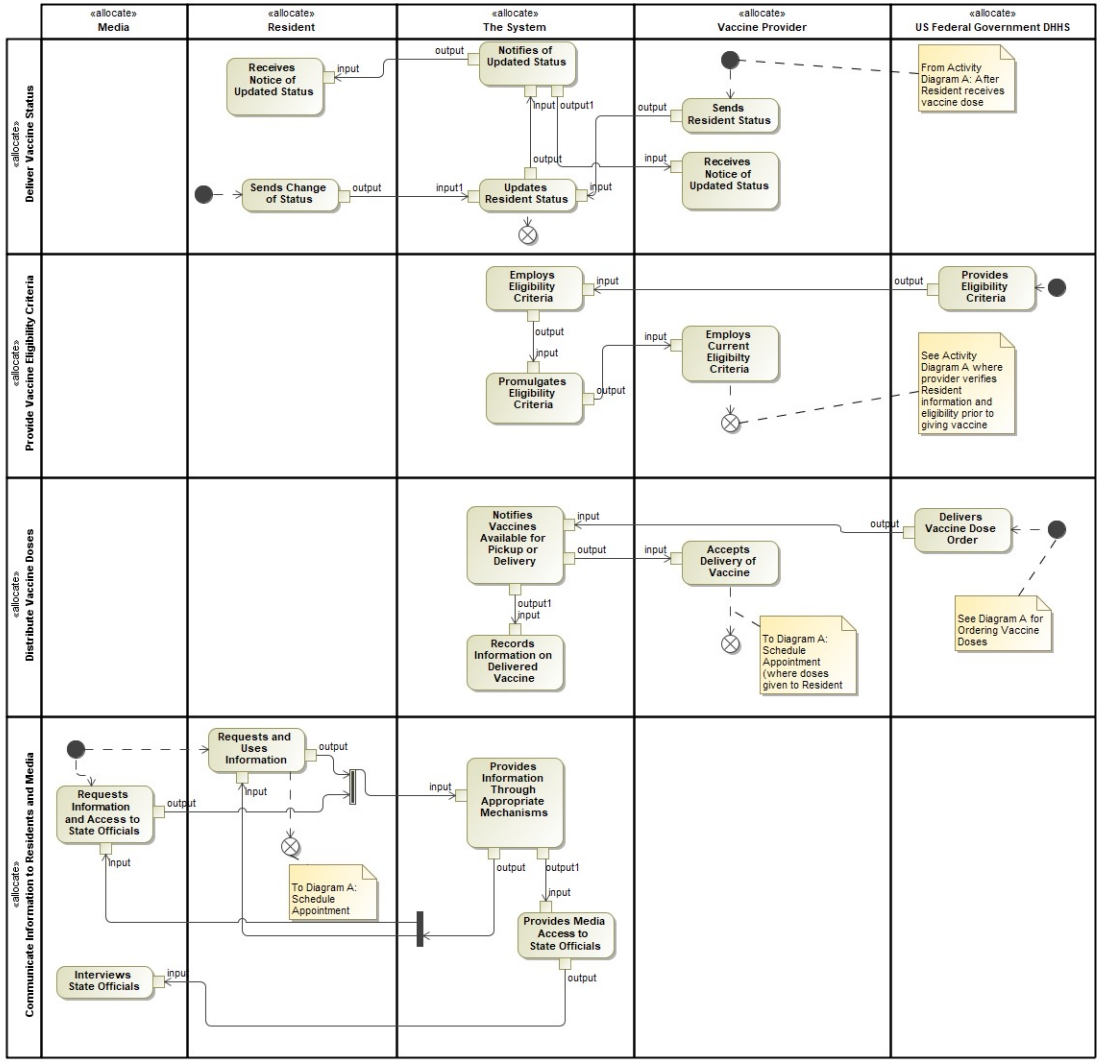
| Use Case: | Narrative |
|---|---|
| Description | |
| Author | |
| Version | |
| Date | |
| Assumptions | |
| Actors | |
| Pre-Conditions | |
| Triggers | |
| Main Success Scenario | |
| Post Conditions | |
| Exceptions | |
| Requirements | |
| A. Functional | |
| A. Performance | |
| A. Non-Functional | |

| Use Case: REGISTER FOR VACCINE[1] | Narrative |
|---|---|
| Description | Resident registers with a vaccine provider and obtains an appointment or appointments to receive a dose or doses. |
| Author | S J Sutton |
| Version | 1.7.1 |
| Date | 12 May 2022 |
| Assumptions | 1. Resident has knowledge of how to access the System to make an appointment<br>2. Resident has access to a PC, tablet, smartphone, telephone, or a simple cell phone (not "smart") (If not, see Assumption 4)<br>3. Resident resides in the state[2] and meets the criteria for receiving the vaccine (e.g., age[3], health condition, occupation, location)<br>4. Resident has access to someone[4] or some organization that has access to communication devices<br>5. Mechanism through which to register is the *Deliver Vaccines to Residents of a US State* – i.e., the System<br>6. The System safeguards a Resident's protected personal information (PPI) and medical information (HIPAA) from disclosure to unauthorized individuals or organizations.<br>7. CDC establishes current eligibility criteria to be applied by the System and Vaccine Providers.<br>8. Vaccine Providers provide the System with their locations and appointment slots (dates/times).<br>9. The System becomes the source of record for all appointment times and status (available/reserved). |
| Actors | 1. Resident – a resident of the state (someone whose domicile has an address within the state) |
| Pre-Conditions | 1. Vaccine eligibility criteria established<br>2. A process and mechanism established to register for vaccine<br>3. The process and mechanism advertised to Residents via various media |
| Triggers | 1. Resident decides to get vaccinated, a second shot, or a booster shot (any dose above the initial one or two doses).<br>2. Resident finds how to access to the System.<br>3. The Resident (or designated representative) accesses the System via a communications device (PC, tablet, smartphone, telephone, or simple cell phone) |

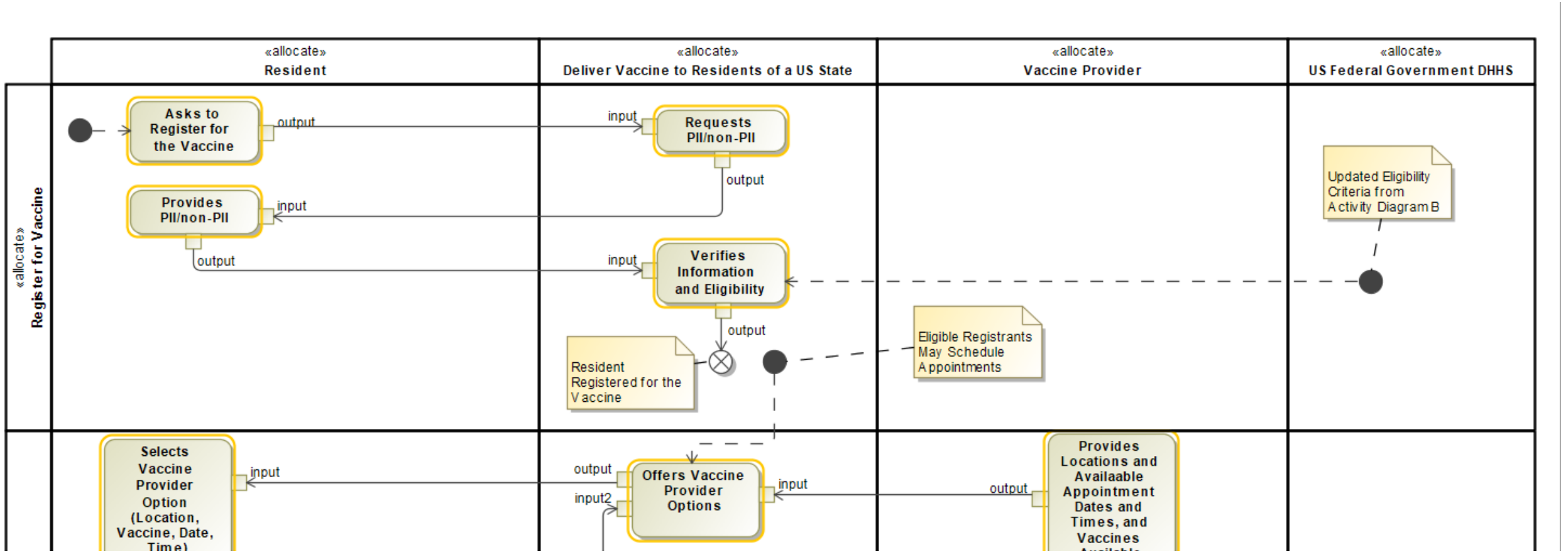
| | |
|---|---|
| Main Success Scenario | Step 1: The Resident asks to register for the vaccine.<br>Step 2: The System asks for the Resident to provide or verify Personal Identifiable Information (PII and non-PII) and/or HIPAA protected information required to register for the vaccine (name, address, health insurance, health conditions (to include whether Resident had recovered from COVID-19 within the previous 90 days), COVID-19 vaccination status: none, one shot, two shots, additional shots and vaccine type – Pfizer or Moderna or J&J or TBS)<br>Step 3: The System verifies Resident eligibility and retains the Resident's information. (This constitutes registration.) |
| Post Conditions | 1. The Resident has registered for the vaccine<br>2. The System offers the Resident appointment opportunities (see Schedule Appointment UC) |
| Exceptions | 1. Resident not Eligible<br>2. Resident had prior vaccine dose or doses in another State or Country<br>3. Walkup Registration / Appointment |
| Requirements | |
| A. Functional | 1. The System shall register Residents for the vaccine.<br>2. The System shall hold the Residents' information and vaccine status. |
| B. Performance | 1. The System shall provide access to registration within TBD seconds for Residents who register via a "smart" communications device.[1]<br>2. The System shall provide access to registration within TBD seconds for Residents who register using a telephone (voice).<br>3. TBD |
| C. Non-Functional | 1. The System shall protect the information it holds against unauthorized disclosure IAW HIPAA and TBD.<br>2. The System shall have an Availability of TBD. |

# Defining Information Flows and Relationships: Activity Diagrams

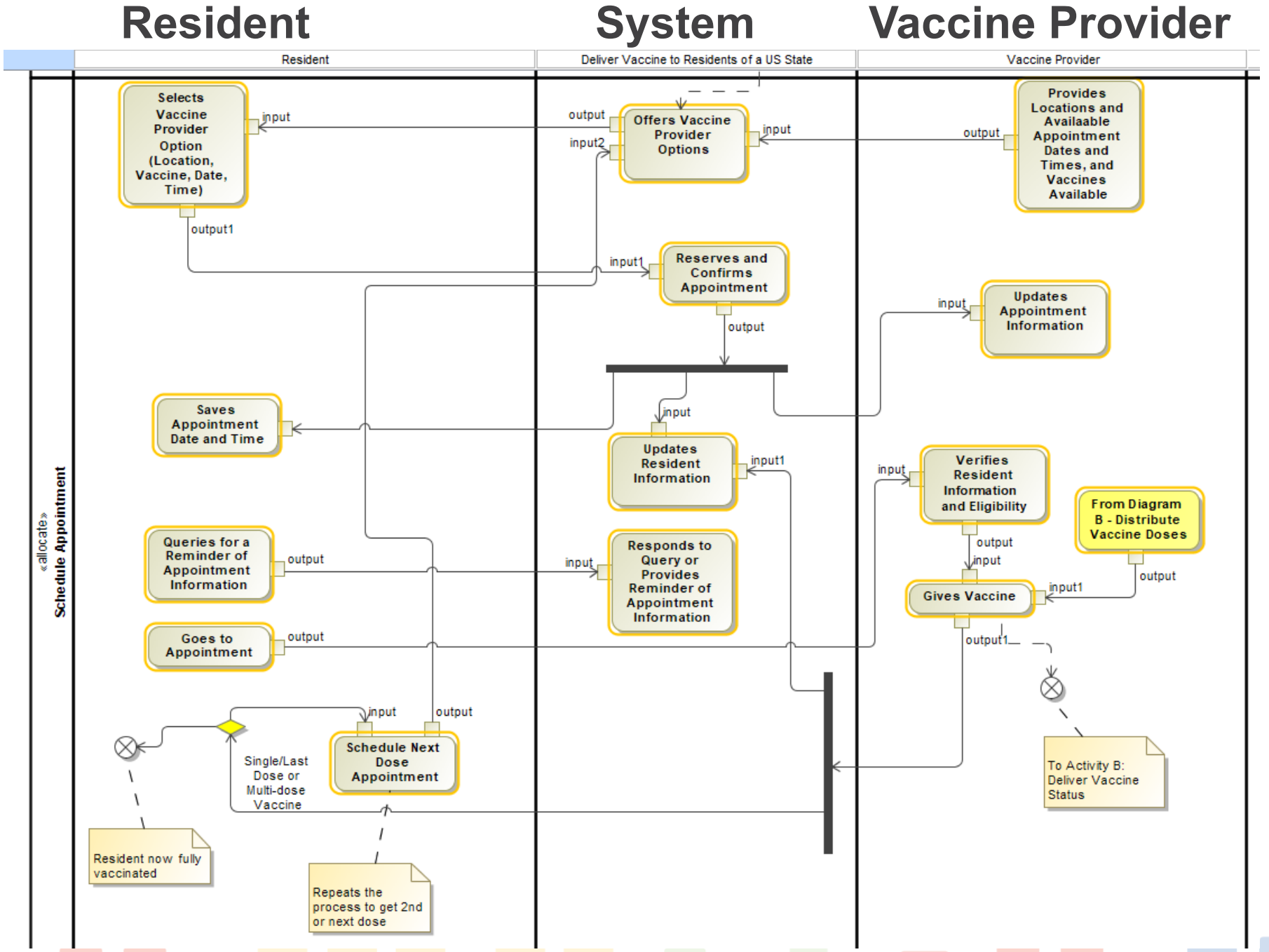




# Register for Vaccine



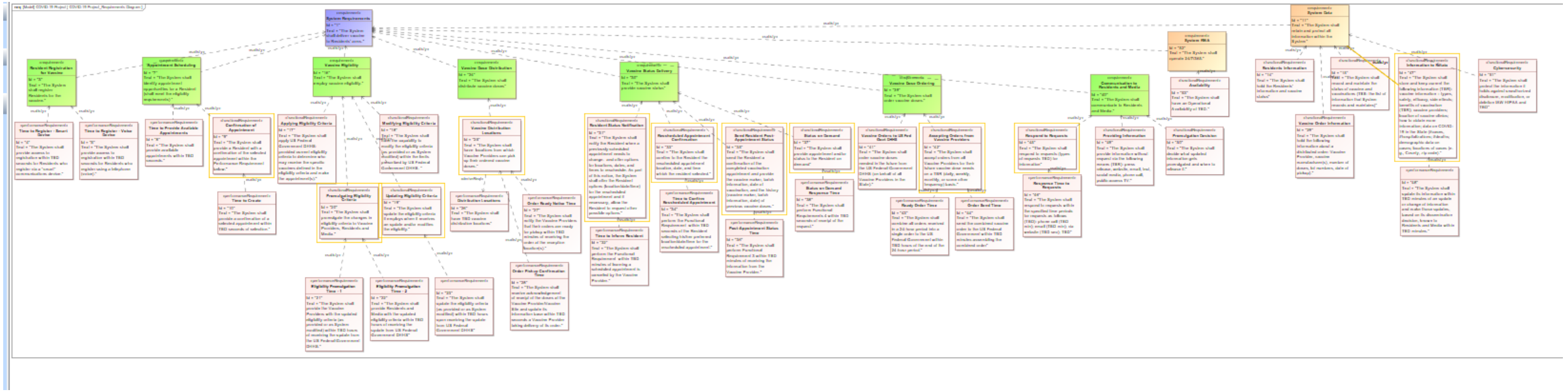
# Schedule Appointments



# System Requirements – Initial Set

- Stated requirements while developing the Use Case Narratives
- Culled out repetitive requirements
- Created a Requirements Diagram

# Requirements Diagram



**Resident Registration for Vaccine**

**Appointment Scheduling**

**Vaccine Eligibility**

**Vaccine Dose Distribution**

**Vaccine Status Delivery**

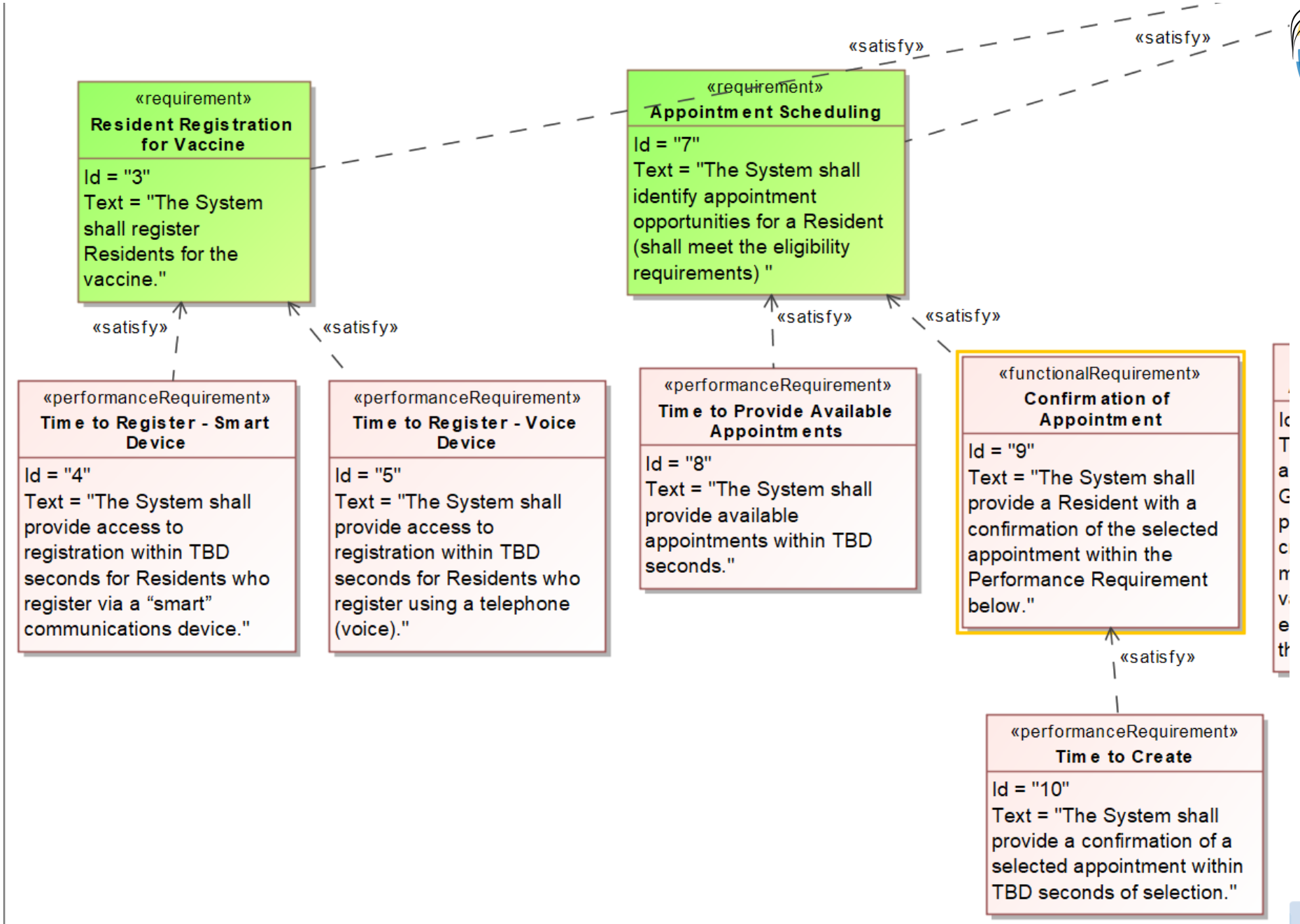
**Vaccine Dose Ordering**

**Communications to Residents and Media**

**System RMA**

**System Data**

# Requirements: Registration and Appointment Scheduling



# Simulation

- Motivation is to provide capability to test system design under different scenarios
- Questions
  - Does the system have enough capacity?
  - Does the system have barriers to vaccination?
  - Does the system support various requirements and performance measures?
    - Acceptable percentage of patients accommodated with appointments
    - Acceptable time between appointment scheduling and appointment
    - Time constraints between 1st and 2nd shots
    - Cold storage requirements for doses
    - Dose spoilage minimization

# Simulation Platform

- Simulation of vaccine scheduling and delivery and administration process
  - Not considering IT requirements for scheduling system
- Discrete-event and agent-based platforms
- AnyLogic selected
  - Supports both discrete-event and agent-based models
  - Java-extensible

# Simulation Prototype

- Purpose is to provide a small-scale prototype of how simulation can be used
- Simulation model should be consistent with SysML model diagrams
- Automated simulation model creation from SysML models is an area of future research
- Data-driven model based on scenario

# Simulation Components

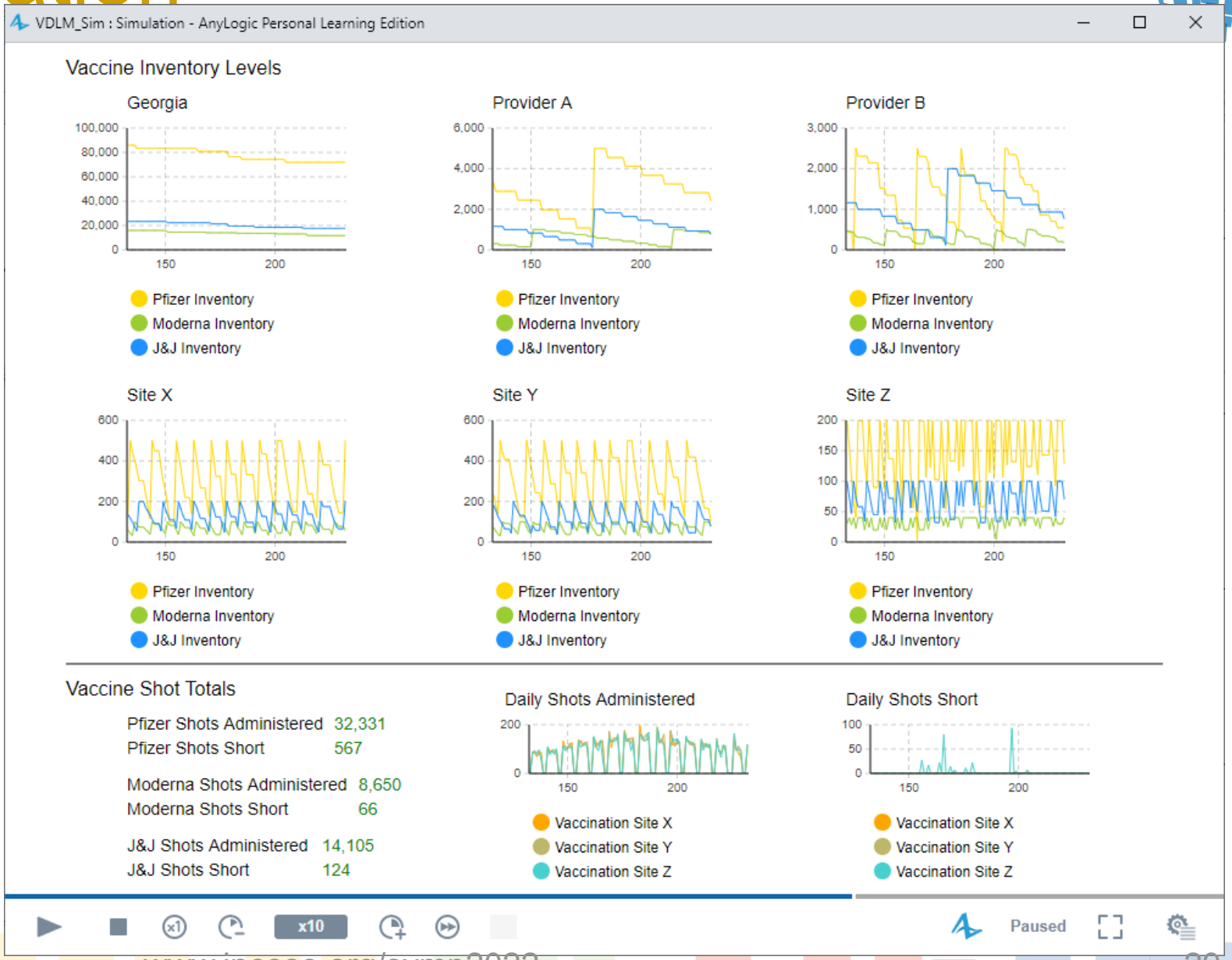
- Patients
- Appointment calendars
- Vaccination centers
- Vaccination providers
- Vaccine doses
- Eligibility criteria

# Initial Scenario

- 3 Vaccine Providers
- 8 Vaccine Sites
- 1st and 2nd shots (no boosters)
- 1,000 patients
- Vaccine inventory model with replenishment from government
- Patient appointment scheduling model

# Prototype Simulation Dashboard

- Vaccine dose inventory model
- Vaccine shot totals over time
  - Administered
  - Short



# Simulation Demonstration

- Video of simulation

# Long-Range Simulation Goal

- Provide simulator with dashboard having
  - Controls for scenario specification
  - Visualizations for system performance/status over time
  - Statistical output for comparative analysis

# Takeaways

- You can’t define a system without collaboration – it takes a team
- To use a tool effectively, need to understand how to best use the tool
- Understand how the tool supports your systems thinking paradigm – adjust, but don’t let the tool override your thinking process

# Moving Forward

- Need volunteers to take the design process further
- Engaging a state, local, or tribal health department to determine if this project can be a reference model for a system

# Contact Information

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- Doug Bodner – doug.bodner@gatech.edu
- Steve Sutton – sjsutton.243@comcast.net
- CIPRWG Chair: Dan Eisenberg – daniel.eisenberg@nps.edu

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