SMART COLUMBUS

Systems Engineering Management Plan for the Smart Columbus Demonstration Program

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16. Abstract

The Smart City Demonstration Program is intended to improve access through expanded mobility options in major job centers, enhance visitor experience by better connecting visitors to transportation options, stimulate regional economic prosperity and compete globally through smart logistics, better connect Columbus residents to safe, reliable transportation that can be accessed by all, and support the efficient movement of people and goods through environmentally sustainable practices.

This document enables the Smart Columbus Project Team to manage the overall Smart Columbus program and each of its associated projects using consistent systems engineering principles and methodologies to maximize the quality of each system while adhering to the budget and schedule. The SEMP provides a process to manage the relationship between Program and Project objectives, the sequence of Projects, the dependencies of Projects, consistent execution of Projects, identification of common resources, and establishment of a management hierarchy between Program and Projects.

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Chapter 1. Introduction

The Smart Columbus program is an integrated and holistic demonstration that will help all residents have more mobility options and access opportunities. The program consists of nine projects which are described in the Smart Columbus Project Management Plan (PMP) and later in this document. The Smart Columbus program will demonstrate how advanced technologies can be integrated into other operational areas within the City, utilizing advancements in intelligent transportation systems (ITS) and connected vehicles (CV), automated vehicles (AV), and electric vehicles to meet these challenges, while integrating data from various sectors and sources to simultaneously power these technologies while leveraging the new information they provide.

To be successful, the program requires a rigorous, well-defined, and holistic Systems Engineering Process (SEP) to support the planning, design, deployment, operations, and maintenance of the ITS and advanced technology projects that will be demonstrated. These projects will be deployed together in the City of Columbus as a cohesive, integrated system-of-systems to meet public and stakeholder needs.

1.1 Scope of the Systems Engineering Management Plan

The scope of this System Engineering Management Plan (SEMP) is to document the SEP the City of Columbus will follow to deliver a successful Smart Columbus program. The SEMP enables the Smart Columbus Program Office to manage the overall Smart Columbus program and each of its associated projects using consistent systems engineering principles and methodologies to maximize the quality of each system while adhering to the scope, budget, and schedule. Benefits of having a well-defined SEP include:

- Improved stakeholder participation
- More adaptable, resilient, and interoperable systems
- Verified functionality and fewer defects
- Replicability and continuity with subsequent projects
- Better documentation[1]

1.2 Intended Audience

The Smart Columbus program team includes staff from the United States Department of Transportation (USDOT), the City of Columbus, their contractors, partners, and stakeholders, and independent evaluation teams. This SEMP is intended to provide the entire Smart Columbus team with detailed information regarding the systems engineering activities at both the program and individual project level, specifically discussing:

[1] https://ops.fhwa.dot.gov/publications/seitsguide/section2.htm#s2.1

- The process to manage the relationship between program and project objectives
- The project sequence and dependencies
- The identification of common resources,
- The management hierarchy between program and projects

The SEMP identifies resources, processes, and methodologies that can be referenced by the USDOT, Program Managers (PgMs) and Project Managers (PMs) to quickly identify the right team structure, process, documentation, and deliverables, as well as the interdependencies among them.

1.3 SEMP Update Process

The Smart Columbus SEMP will be a living document. As the program evolves and the team acts on the described activities and process, some elements may require refinement to ensure a quality and sustainable system is deployed. The SEMP will be updated as needed to accommodate these changes and refinements to ensure that the Smart Columbus project team understands and continues to follow SE processes that will result in successful program outcomes. This document will be reviewed quarterly to maintain alignment with the PMP and reflect the decisions made during major milestones in the Concept of Operations (ConOps), System Requirements (SyRS), procurement, design, testing and deployments. As the second revision of the SEMP, this document has been reorganized to reflect the latest PMP (November 2017) as well as the Project Advancement Approach discussed with USDOT.

1.4 Relation to the PMP

The SEMP describes the technical activities; specifically, the SE processes, responsibilities, and methodologies used on the projects and the relationship of these activities to other project activities. The PMP is the overall master planning document for the Smart Columbus program and includes many disciplines beyond SE. The PMP is a formal document used to manage project execution. The PMP documents the actions necessary to define, prepare, integrate and coordinate the various planning activities. The PMP defines how the project is executed, monitored and controlled, and closed. The PMP describes all activities, including technical activities, to be integrated and controlled during the life of the program. The SEMP outlines the technical plans and systems engineering activities that will be used to develop, integrate, test, validate and deploy the Smart Columbus projects. Developed early in the SE process as a supplement to the PMP, the SEMP uses the foundation laid by the PMP to build the framework for executing the SE technical tasks for the program and individual projects.

Both documents are important in terms of understanding and managing the scope of work, how to plan for critical activities, how to manage efforts while reducing risk, and how to successfully complete deliverables. The SEMP must be consistent and evolve in concert with the PMP. They must complement each other and be cross-referenced. They should consistently define the roles and responsibilities of the technical and management staff, the processes for planning and monitoring technical activities, and identifying and mitigating program and technical risk. The main difference is that the PMP includes all activities to be integrated and controlled during the life of the program, whereas the SEMP emphasizes the SE activities that are important to the program and individual projects.

The City Program Manager (PgM) and Consultant PgM will resolve differences between the PMP and the SEMP on a case by case basis to determine which document takes precedent. Changes to either

document will be logged as they are identified and incorporated into the next quarterly update to the appropriate document.

1.5 Overview of the Document

The document is organized to provide the SE management approach at both the program and project level. This approach is anchored by regular project-level coordination meetings to maintain project progress and regular program-level Scrum of Scrum[2] meetings (see Section 3.2.2 below) to ensure the projects are integrated and all dependencies are discovered, tracked, and considered during development of the program.

The USDOT encourages the use of SE as a structured approach to successfully complete ITS projects[3]. SE reduces the risk of schedule and cost overruns and increases the likelihood that the implementation will meet the user's needs.

Given the value of the structured approach, the SEMP for the Smart Columbus program will:

- Outline the framework for all SE tasks associated with the program
- Provide the technical plan of the program and the processes used to accomplish it
- Provide detail regarding the engineering tasks, especially detailed information on the processes to be used for gathering and preparing user needs, defining requirements, etc.
- Identify the needed tasks (including analysis tasks) and any constraints on the performance of a task (such as use of a specific SE and design methodology)

The SEMP begins with an overview of the program (updated as of September 2017), and provides an overview of how the engineering activities at the program level will be managed. The document also details how each of the projects relate, contribute and integrate to the Smart Columbus program, and how the user needs for each will be will be evaluated and completed before moving into the design and development activities. Finally, the SEMP summarizes how all SE activities will be documented at both the program and project level.

[2] "Scrum" is defined in this document, Section 4.1.2.1. Scrum is an Agile team-based process guided by individuals and interactions over processes and tools, working software over comprehensive documentation, customer collaboration over contract negotiation and responding to change over following a plan.
[3] https://www.fhwa.dot.gov/legsregs/directives/fapg/cfr0940.htm

Chapter 2. Smart Columbus Scope and Goals

2.1 Strategic Framework

The Smart Columbus vision strives to empower residents to live their best lives through responsive, innovative, and safe mobility solutions with a supporting mission to demonstrate how ITS and equitable access to transportation have positive impacts on every day challenges faced by cities. The PMP articulates four outcomes of the Smart Columbus program, including:

- Improve Safety**:** The City of Columbus wants to create safer streets where vehicles, cyclists, and pedestrians are less likely to be involved in accidents.
- Enhance Mobility**:** The City of Columbus wants to make traversing the City and parking as efficient and convenient as possible.
- Enhance Access to Opportunities & Services**:** The City of Columbus wants to make multi-modal transportation options and the ability to access them equally available to all residents, especially those who need access to opportunities related to health care, jobs, school, and training.
- Reduce Environmental Impact**:** The City of Columbus wants to reduce the negative impact transportation has on the environment through becoming more efficient and embracing multi-modal options.

Additionally, the draft Performance Measurement Plan provides two outcomes applicable to the projects being developed as part of the demonstration, identified as:

- Agency Efficiency: Columbus wants to provide tools and access to the data generated by the projects to improve operations and efficiency of city services.
- Customer Satisfaction: Columbus wants to provide resources and information to the citizens to increase their satisfaction with city services through the use and application of technology.

These additional outcomes especially relate to the potential impact of the Smart Columbus Operating System (SCOS) and the overall Smart Columbus vision to empower residents (customers). As part of the next quarterly PMP update, a consolidated list of all outcomes will be provided to be consistent among the PMP, SEMP, and future deliverables such as the Performance Measurement Plan (PfMP).

Table 1 below identifies the relationship between the various demonstration projects and the potential outcomes. The outcomes will be evaluated based on the PfMP.

Table 1. Project Outcomes

SMART COLUMBUS PROJECTS	Safety	Mobility	Opportunity	Environment	Agency Efficiency	Customer Satisfaction
1. Smart Columbus Operating System (SCOS)					X	X
2. Connected Vehicle Environment	X	X				X
3. Multi-Modal Trip Planning Application/Common Payment System		X	X			X
4. Mobility Assistance for Cognitive Disabilities		X	X		X	X
5. Prenatal Trip Assistance		X	X		X	X
6. Smart Mobility Hubs		X	X			X
7. Event Parking Management		X		X		X
8. Connected Electric Automated Vehicle	X	X	X	X		X
9. Truck Platooning		X		X		
Total	**2**	**8**	**5**	**3**	**3**	**8**

2.2 Program Overview

Smart Columbus is taking a district-oriented approach to best demonstrate effective implementation of a comprehensive portfolio of connected technologies that solve focused, relatable city issues and enhance mobility across the region. Four deployment districts were strategically identified based on the unique problem-solving proving ground they offer which creates a foundation of nationwide scalability. The districts are identified below, while the PMP contains a detailed description of each one.

1. Residential (Linden)
2. Commercial (Easton)
3. Downtown
4. Logistics (Rickenbacker International Airport

The district/project deployment maps are shown in Figure 2 of the PMP. While there are unique and distinct deployment districts, many projects will also be deployed citywide and be designed in an integrated manner with the SCOS being the integral backbone and heart of all current and future smart city projects.

The eight other Smart Columbus projects fit into three overarching themes. As with the districts, a detailed description of these themes is contained in the PMP.

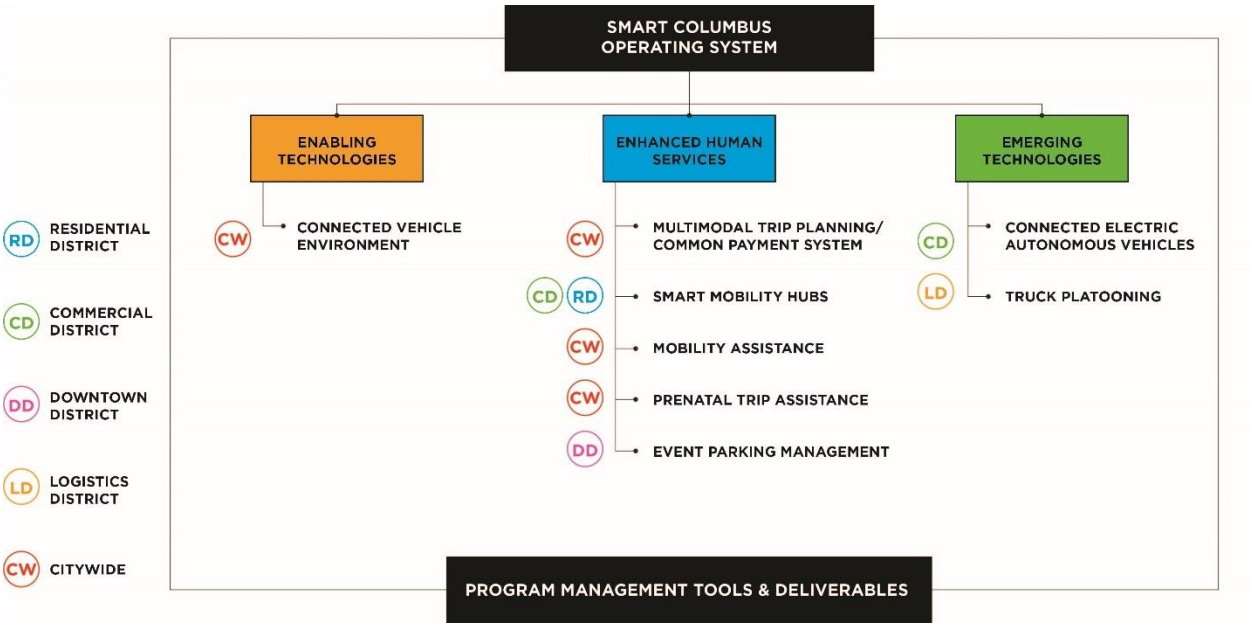
- Enabling Technologies: These technologies leverage today's foundation in new and innovative ways to greatly enhance the safety and mobility of the transportation infrastructure.
- Enhanced Human Services (EHS): These services encompass meeting human needs through the application of technology that focuses on prevention as well as remediation of problems.
- Emerging Technologies: New technologies that are currently developing or will be developed over the next five to ten years, that may substantially alter the business and social environment.

2.2.1 Project Descriptions

Figure 1 summarizes the SCOS and portfolio of USDOT projects. It depicts the essential nature of the SCOS and ties the three themes, as well as their supporting projects, together. It also indicates the documentation and management of the overall program, anchored by the tools and documentation used in coordination and cooperation between the City and USDOT. Program-level documents including the PMP, SEMP and Performance Measurement Plan (PfMP) – among others – are included under "program management tools and deliverables."

2.2.1.1 Smart Columbus Operating System

The SCOS is envisioned as a web-based, dynamic, governed data delivery platform built on a federated architecture that is at the heart of the Smart Columbus system. It will ingest and disseminate data while providing access to data services from multiple sources and tenants, including the planned Smart Columbus technologies, traditional transportation data and data from other community partners, such as food pantries and medical services. The SCOS will embody open-data, best-of-breed technologies including open-source and commercial off-the-shelf concepts that enable better decision-making and problem solving for all users. It will support a replicable, extensible, sustainable data delivery platform. The SCOS will be the source for performance metrics for program monitoring and evaluation, serve the needs of public agencies, researchers and entrepreneurs, and assist health, human services organizations, and other agencies in providing more effective services to their clients. The SCOS will be scalable and demonstrate the potential for serving city and private sector needs well beyond the life of the Smart City Challenge (SCC) Award period.



Source: City of Columbus, October 2017

Figure 1. Smart Columbus Framework

2.2.1.2 Enabling Technologies

2.2.1.2.1 Connected Vehicle Environment

There are corridors and intersections in Columbus that have high crash numbers with vehicles, bicyclists, and pedestrians. In addition, there are several congested corridors that result in poor mobility conditions for emergency vehicles, freight, and transit buses. The CVE corridors were selected based on regional crash data, enhanced transit services, recent infrastructure investments, and relationship to other projects. For example, the CVE corridors have 17 intersections in the top 100 regional high-crash intersections.

The anticipated outcomes of the CVE project are to enhance safety and mobility throughout the City's transportation system using CV technologies and applications with an emphasis on congested and high crash intersections and corridors. Safety applications are intended to be installed on multiple vehicle types including transit buses, first responder vehicles, city, and partner fleet vehicles and private vehicles. Applications will be deployed to ensure the Central Ohio Transit Agency (COTA) Bus Rapid Transit (BRT) fleet can utilize signal prioritization when needed to ensure safety and customer satisfaction.

2.2.1.3 Enhanced Human Services

2.2.1.3.1 Multi-modal Trip Planning Application/Common Payment System

Columbus residents and visitors do not have access to a system for seamless planning of or paying for a trip involving multiple transportation service and parking providers. Moreover, some Columbus residents are unbanked and therefore cannot access alternative modes of transportation, including car and bike sharing systems. The Multi-modal Trip Planning Application (MMTPA) will make multi-modal options easily accessible to all by providing a robust set of transit and alternative transportation options including routes, schedules, and dispatching possibilities. The application will allow travelers to request and view multiple trip itineraries and

make reservations for shared-use transportation options such as bikeshare, transportation network companies, and car share. Using the MMTPA, users will be able to compare travel options across modes, plan, and pay for their travel based upon current traffic conditions and availability of services. Payment for transportation service and parking providers will be processed through a Common Payment System (CPS) that may be the first of its kind in the United States. It is the City's goal that this application will allow residents to more easily access the transportation systems available in Columbus today and in the future. This project is anticipated to provide an innovative solution to improve mobility and access to opportunity.

2.2.1.3.2 Mobility Assistance for People with Cognitive Disabilities

Mobility assistance is needed to provide more independence to residents with cognitive disabilities. Persons with cognitive disabilities who wish to independently use public transit services in Columbus must either qualify for special paratransit services in accordance with federal law, or they must be sufficiently independent to safely use fixed route bus service without assistance. The City's goal is to develop and deploy an application that would allow this population to independently traverse the City via COTA's fixed bus route system. The mobile application will be a highly-accurate, turn-by-turn navigator designed to be sufficiently intuitive such that older adults and groups with disabilities, including the cognitively and visually disabled, can travel independently.

This project provides an opportunity for users to empower themselves and gain mobility independence, relying less on caregivers or COTA paratransit system for transportation.

2.2.1.3.3 Prenatal Trip Assistance

Columbus has one of the highest infant mortality rates in the country, which is partially caused by expectant mothers not getting necessary prenatal healthcare. The existing Non-Emergency Medical Transportation (NEMT) system does not always provide reliable round-trip transportation. Linden residents have challenges accessing healthcare services due to the current NEMT model and technologies. It is the City's goal to work with Franklin County and Celebrate One to develop a means for bridging the gap among healthcare providers, expectant mothers, and NEMT services that are paid for through the Medicaid system.

This project will be further vetted with key stakeholders to identify goals and measurable objectives. A driving force for this project is the need to provide a more streamlined and efficient NEMT system to improve mobility and satisfaction for users.

2.2.1.3.4 Smart Mobility Hubs

Currently, there is no enhanced mobility or multi-modal transit features to alleviate FMLM challenges in the Linden area or along the Cleveland Avenue corridor. The vision for this project is to transform some COTA bus stops along the BRT CMAX corridor and transit centers into Smart Mobility Hubs (SMH), where someone entering or exiting the bus can easily access the next leg of their trip. The City plans to outfit the hubs with kiosks to assist travel planning and expand transportation options via other modes, such as bike- and car-sharing. The SMH will be linked with COTA systems to provide transit information with real-time arrival and departure data to the passengers waiting at the hubs. This project will also explore the utility of these hubs in additional districts, in particular the commercial district, which faces similar FMLM challenges in connecting travelers to their destinations.

This project provides an opportunity for residents and visitors to access multiple modes of travel to solve FMLM challenges.

2.2.1.3.5 Event Parking Management

The City of Columbus lacks an integrated system for residents and visitors to easily and efficiently view available parking spaces at parking garages, surface lots, and parking meters, especially at large events. Non-direct routing of travelers causes congestion and inefficiency in the transportation network. The City's goal with Event Parking Management (EPM) is to integrate parking information from multiple providers into a single availability and reservation services solution. This will allow travelers to plan and search for parking options at certain locations to reserve and book a parking space with the CPS. More direct routing of travelers during large events is expected to reduce congestion during those times.

2.2.1.4 Emerging Technologies

2.2.1.4.1 Connected Electric Autonomous Vehicles

In the Easton area, many businesses and retail centers are more than one mile from current COTA bus stops, which is longer than a typically acceptable walking distance from transit. The City's goal is to connect COTA riders to opportunities in the Easton area. In addition, the City aims to reduce congestion in the Easton area by encouraging visitors to "park once." The Connected Electric Autonomous Vehicles (CEAVs) will be deployed to meet these goals, and are expected to operate in a mixed-traffic environment, interacting with other vehicles, bicyclists, and pedestrians. The project provides an accessible and easily expandable FMLM transportation solution to the region by deploying a fleet of multi-passenger EAVs that leverages the enhanced connectivity provided by the CVE and city-wide travel planning and payment solutions.

The implementation of this innovative FMLM solution also expands the reach of the new CMAX BRT system immediately to the west of this location, and the deployment of smart connected intersections throughout the region, allowing more efficient traffic flow to, from, and within the region. The potential routes for the CEAVs include both work-center and retail-center shuttles. Work center shuttle routes will be synchronized with the schedules of local employers and the COTA fleet, and will likely start and end at the COTA Transit Center. The retail shuttle will operate within the confines of the retail area, serving the largest parking facilities and retail areas. These routes are still under development and may be altered depending on the feasibility of running CEAVs on certain roads, and considering current travel behavior and potential passenger demand.

2.2.1.4.2 Truck Platooning

Freight-induced congestion and queuing are significant challenges within Columbus. Logistics providers need more safe, efficient, and environmentally beneficial ways to deliver goods. The City's goal is to ensure efficient and safe movement of logistics-related vehicles using ITS. Specifically, freight signal prioritization on CV-enabled trucks will be deployed to reduce freight-induced congestion and queuing.

In addition, multiple two-vehicle CV-enabled truck platoons will be deployed from Columbus to the eastern Ohio area. Wireless communications will be added to existing vehicle technologies to allow trucks to reduce their headways when traveling on freeways. On arterials, these vehicles will receive platoon intent signal priority enabling two trucks to traverse an intersection during the same signal phase cycle. Platooning is expected to save fuel and reduce vehicle emissions.

Chapter 3. Systems Engineering Management

3.1 Engineering Plan Oversight/Roles & Responsibilities

The City of Columbus' Smart Columbus Program Management Office (PMO) will serve as the overall program owner providing oversight and direction to the project teams as needed. Individual city departments and the local transit agency will serve as the product or business owners, responsible for prioritizing the engineering team's activities. 'Product owner' is consistent with Agile projects whereas 'business owner' applies to V-Model projects; Agile and V-Model will be defined and discussed in Chapter 4 of this document.

Table 2 identifies the entity that will be the product or business owner for each project. The PMP (specifically, Table 1) identifies the main point of contact within each product/business owner organization. For those projects that have an external entity (outside of the City), the agency point of contact will designate a lead to participate as a member of the individual project team. This will ensure that the owner's interests are met during the development and deployment of the solution. These staff are currently to-be-determined, but will be noted in the PMP once assigned.

Table 2. Project Product/Business Owners

Project	Product/Business Owner	Product/Business Owner Representative
Smart Columbus Operating System	City of Columbus Smart Columbus PMO	Michael Stevens (City)
Connected Vehicle Environment	City of Columbus, Department of Public Service/ Division of Traffic Management	Jennifer Gallagher (City)
Multi-Modal Trip Planning / Common Payment System	City of Columbus Smart Columbus PMO	Michael Stevens (City)
Smart Mobility Hubs	Central Ohio Transit Authority	Michael Carrol (COTA)
Mobility Assistance	Central Ohio Transit Authority	Michael Carrol (COTA)
Prenatal Trip Assistance	Franklin County (CelebrateOne)[4]	Erika Jones (City)
Event Parking Management	City of Columbus, Department of Public Service/ Division of Traffic Management	Jennifer Gallagher (City)

[4] Franklin County Greater Columbus Infant Mortality Task Force

Project	Product/Business Owner	Product/Business Owner Representative
Connected Electric Automated Vehicles	Central Ohio Transit Authority	Michael Carrol (COTA)
Truck Platooning	City of Columbus, Department of Public Service/ Division of Traffic Management	Jennifer Gallagher (City)

Each project has a City Project Manager (PM), who is responsible for delivery of the overall project, including deliverables, scope, budget, risks, schedule, and policy. They coordinate closely with a consultant Project Lead, who provides the technical leadership for the project. An overall program-level Lead Systems Engineer from the consultant team will have the general responsibility of coordinating the engineering processes and overall technical aspects for the program. The PMO also contains Systems Engineer/Quality Support contractor (SE/QS) who will report directly to the Smart Columbus Program Manager (PgM). The SE/QS will provide review and guidance to the PMO regarding all program and project level SE activities, ensuring consistency among the approach, integration among all projects and that sound SE practices and documentation are applied.

Project-level SE roles and responsibilities will be defined in more detail in Chapter 4, which defines roles and responsibilities specific to the V-Model and Agile Engineering Processes, respectively. The same role identified in each section may have slightly different responsibilities depending on the engineering process. For example, in projects using the V-Model, the business owner is expected to provide direction and goals to the project team as well as prioritize work items. In projects using the Agile process, the product owner is expected to provide direction and goals to the project team and prioritize work items as well as participate in daily scrum meetings throughout the Sprints.

Both program and project-level SE staff and their responsibilities are summarized in Table 3, while Figure 2 presents the overall organizational structure for the Smart Columbus program.[5] As projects progress, additional skill sets may be required that are beyond the capabilities of the staff listed in Table 3 and Figure 2. In such cases, the City will use additional personnel with the required skill set(s) internally or within its consultant team. In the event individuals are not identified within the City or consultant team, the City may obtain additional resources.

Table 3. Engineering Oversight – Roles and Responsibilities

Role	Description
Program Level	
Chief Innovation Officer (CINO)/Program Owner (City)	Accountable for the entire Smart Columbus program and enterprise-wide program management framework. Accountable for developing and implementing citywide innovation solutions aligned with the mayor's priorities.

[5] The PMO structure for Smart Columbus shown in Figure 2 is also contained in the PMP.

Role	Description
Deputy CINO (City)	Directly supports the CINO's vision for innovation including enterprise-wide program management and citywide innovation solutions. Serves as acting CINO in CINO's absence. Responsible for strategic partnerships and relationships.
Program Manager (PgM) (City)	Responsible for overall delivery of the program. This includes adding expertise to the team as needed to ensure delivery. Responsible for PMO leadership and processes, scope, schedule, budget, policy, reporting, and risk management for the overall Smart Columbus program and the primary interface to the USDOT team.
Deputy PgM (DPgM) (Technology) (City)	Responsible for overseeing Information Technology (IT) elements within each project, ensuring proper representation is engaged for consultation and solution delivery, providing senior level program support for the SCOS project team, overseeing the Data Working Group and deliverables, serves as the voice of IT to the PMO to bridge all projects and Smart Columbus initiatives, and serving as the escalation point for City Department of Technology (DoT) to address project concerns and as the voice to DoT from the PMO.
DPgM (Partnerships and Policy) (City)	Responsible for overseeing the development of partnerships benefitting the USDOT, coordinating partner awards with the PMO, coordinating legislation related to partnerships, managing vendor engagement and tracking, coordinating policy-related issues and assisting with development of policy solutions, overseeing development of procedures for legislation and procurement, and serving as escalation point for partner and vendor issues to PMO.
SE/QS	The SE/QS will serve as a dedicated resource reporting into the PMO looking at project initiatives to ensure they are holistic in approach and tightly integrated with SCOS. The SE/QS will also communicate and coordinate with the Smart Columbus team to facilitate decisions and encourage collaboration. Specific SE activities for this staff including providing review and guidance to the PMO regarding all program and project level SE activities, ensuring consistency among the approach, integration among all projects and that sound SE practices and documentation are applied.
Chief Architect	Responsible for integrating the component applications, managing concept development, design, deployment, testing, operating and maintenance and evaluation, and ensuring all projects and systems can be integrated as designed in the systems engineering documentation, or working to adjust the approach. Serves as an escalation path from the project teams to the PMO and DoT teams for technical issues and decisions that cannot be resolved at the project level (this role is to be determined at this time).

Role	Description
Quality Auditor	The Quality Auditor is responsible for the overall implementation and management of the quality assurance (QA) processes as described in the Quality Management Plan (QMP) Chapter 14 of the PMP. This includes conducting deliverable reviews, ensuring that technical reviewer comments are appropriately adjudicated and resolved, auditing to verify that design packages are in conformance with the Quality Management (QM) section of the PMP. The quality auditor ensures the QM processes are followed, and compiling and maintaining documentation (this role is to be determined at this time).
Information Technology Project Manager (IT PM)	The IT PM is responsible for delivery of SCOS, Data Management Plan and Data Privacy Plan, as well as the lead for data collection, data management, integration, and dissemination. Responsibilities include oversight of deliverables, project scope, budget, risks, schedule, and policy. The IT PM is responsible for engaging the Data Working Group to assist with the evolution of the SCOS. The IT PM is responsible for facilitating IT related escalations, scope variances, policy changes, coordinating between projects, working with partners, and identifying resource needs for the overall success of the project. The IT PM is responsible for is responsible for updating PMO on project status.
Consultant PgM	Responsible for performance of the project leads and technical teams. Conducts technical reviews of all deliverables, monitors quality and performance related to scope, schedule, and budget. Responsible for adding expertise to the team as needed to ensure delivery. Coordinates with the Lead Systems Engineer on the integration of all projects and coordination of engineering activities. Acts as the primary interface to the PgM.
Lead Systems Engineer (Consultant)	Responsible for the overall process of defining, developing, operating, and maintaining the proposed project/system. Ensures the integration of related projects. Organizes and coordinates other engineering activities. Ensures technical accuracy and conformance to relevant SE standards.
Project Level	
Business Owner (V-Model projects)	The designated department/entity expected to continue the operations and support of the respective project at the end of the grant period. Business Owners are informed and consulted throughout the duration of the program. They are responsible for ensuring the PMO considers future project impacts, including operating and capital budgets, business processes, policy, and other support needed to sustain the project beyond the Award period.
Product Manager (Agile projects)	Provides direction and goals for the team and prioritizes tasks. The Product Manager is appointed by the business owner and is empowered to make decisions within a framework of governance defined within the department and independent of the Smart Columbus program. For Agile projects:

Role	Description
	• The Product Manager and development team should engage in continuous user engagement to define and refine user stories. • As progress on the product continues, the Product Manager takes the primary responsibility of grooming (refining and prioritizing) user stories.
Project Manager (PM) - City	The PM is responsible for delivery of the overall project including oversight of deliverables, project scope, budget, risks, schedule, and policy. The PM is responsible for facilitating escalations, scope variance, policy change, coordinating between projects, working with partners, and identifying resource needs for the overall success of the project. The PM is responsible for updating the PMO on project status.
Project Lead (Consultant)	The Project Lead provides technical leadership for the project and has the overall responsibility for delivering a project to the business owner. The Project Lead coordinates tasks within the project team, facilitates and summarizes project meetings and action items, holds the team accountable for deliverables, manages scope, facilitates change management, governs the project per the PMP and SEMP, creates and maintains schedule and risk registers, works with the PM to establish budget and recognize policy needs, and partners with the PM to establish necessary reporting for the PMO/USDOT.
Scrum Master (Agile)	• Leads the Scrum process and oversees how it should be applied • Ensures that the business owner and development team stays within the Scrum process • Coaches the other team members on how to use Scrum in the most effective manner
Scrum Team (Agile)	Consists of five to nine people and generally includes the typical functional roles required to complete the project. The team acts collectively to determine how to achieve their goals. The team participates in Sprint planning meetings, daily scrums, grooming meetings, and Sprint retrospectives. It engages with the Product Manager in continuous user engagement to define and refine user stories.
Technical Team (V-Model)	Responsible for the development of all deliverables following the project scope working under the direction of the Project Manager, Project Lead, and Systems Engineer.
Stakeholders	The International Council on Systems Engineering (INCOSE) defines a stakeholder as “a party having a right, share, or claim in a system or in its possession of characteristics that meet that party's needs and expectations.”[6] For the Smart Columbus program, this includes end users and interested

[6] INCOSE SE Handbook V3.1

Role	Description
	parties who should be consulted and engaged as part of the technical and development processes to ensure projects reflect their wants and needs. For agile projects, stakeholders are the ones who have desires, wants, and needs for data and can help the team understand the value the data brings and use cases for data.
Working Groups	Serve as technical resource advisors to the Smart Columbus project team, which includes the City and consultant team as they develop ConOps, consider end user profiles and needs, and deploy the projects. The working group will meet regularly through completion of ConOps phase and then only as needed beyond ConOps phase.
Subject Matter Expert	Engaged by the PMO to work with the project teams as necessary to offer domain expertise in specified areas to help advance the program and ensure best practices are considered and applied where necessary.

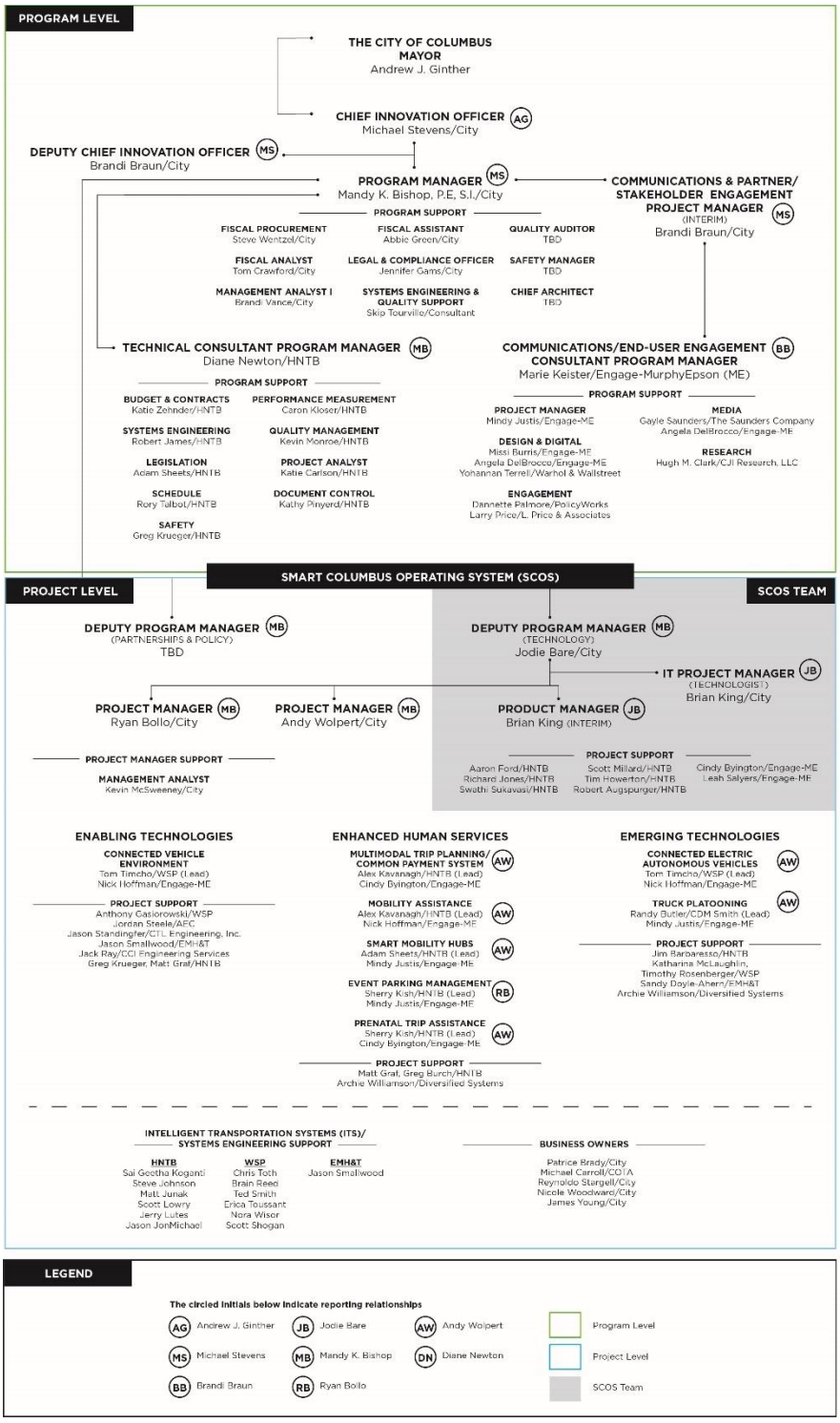
In addition to the frequent internal communication among the project teams, there are several regularly scheduled meetings that will ensure program and project priorities and risks are continually addressed. In addition, there are also regular meetings with the USDOT. All meetings, their owners, attendees, and outcomes are referenced in Chapter 15 of the Smart Columbus PMP. Specific technical meetings that are relevant to the SE activities for both the program and individual projects include:

- Program:
  - Program Leadership Meeting (weekly)
  - Scrum of Scrums Project Management Meeting (semi-weekly)
  - Scrum of Scrum Retrospectives (monthly)
  - USDOT Coordination Meetings (weekly)
- V-Model Project:
  - V-Model Project Coordination Meeting (weekly)
  - (USDOT) Project Team Meetings (bi-weekly)
- Agile Project:
  - Agile Project Sprint Planning Meetings (bi-weekly, prior to first daily Scrum meeting)
  - Agile Project Scrum Meetings (daily)
  - Agile Project Grooming Meetings (bi-weekly)
  - Agile Project Review Meetings (bi-weekly)
  - Agile Project Retrospective Meetings (following Sprint completion)

The City PM, Project Leads, and Lead Systems Engineer will utilize the semi-weekly Scrum of Scrums project management meeting (described in more detail in this section) to collaborate across projects as well as provide feedback and lessons learned when applying the processes and procedures described in this document. The SEMP will be updated as processes and procedures evolve.

The PgM has general oversight for the entire program with individual City PMs having responsibility for their projects. The Lead Systems Engineer, with assistance from the PMs, Program Manager (Consultant) and SE/QS ensures SE practices, methods, and processes are applied consistently across all projects. Project

Leads have the responsibility of applying the appropriate practices, methods, and process for their project with assistance from the Lead Systems Engineer and SE/QS. If an individual on the project team has questions or a gap is identified in a process, the Project Lead, PM, and Lead Systems Engineer will discuss and, if necessary, recommend updates to this document to the PgM and PgM (Consultant). Once the recommendations are approved, the Lead Systems Engineer will update the SEMP accordingly and publish the update on the SharePoint site. Updates will also be communicated during weekly program calls between the Project Leads and the SE staff and be included in the City's Quarterly Report to the USDOT. Figure 2 shows the structure of the Smart Columbus PMO.



Source: City of Columbus, October 2017

Figure 2. Smart Columbus PMO Structure

Whenever changes or modifications are required to the schedule based on the SEMP, the process outlined in the Smart Columbus PMP will be followed. Chapter 7 of the PMP defines the process of identifying, documenting, approving, rejecting, and controlling changes to project baselines. Chapter 8 of the PMP describes the process for modifying the schedule based on updates to the SEMP or any other unforeseen event or complication.

3.2 Program Level System Engineering Approach

At the program level, the Smart Columbus program will adopt a System of Systems (SoS) approach to SE. The SoS consists of the SCOS and the other eight projects, as described in Chapter 2 of this document.

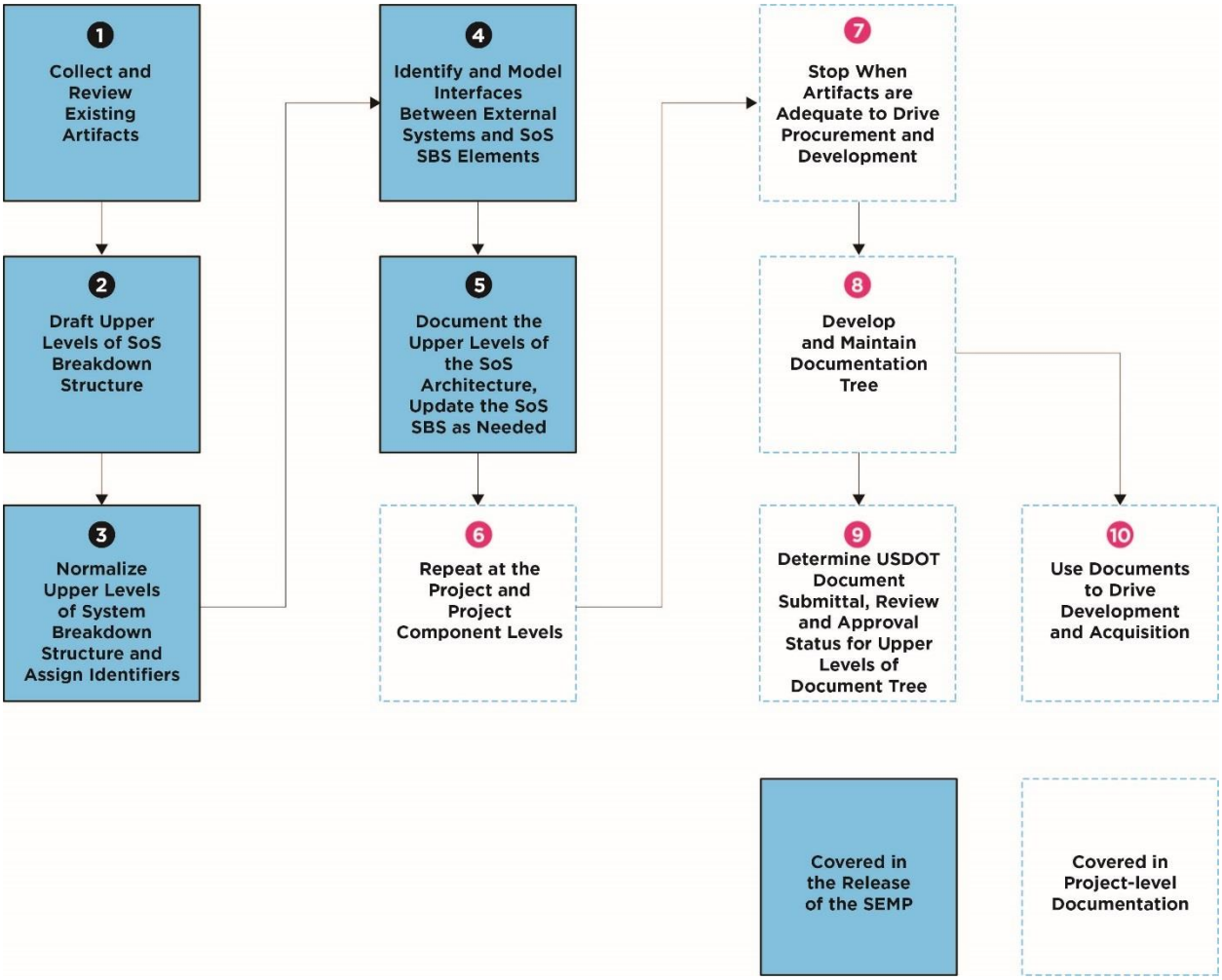
3.2.1 System of Systems

Stakeholder identification and engagement has been underway since January 2017. In September 2017, the USDOT and PMO identified the need for the PMO to revisit and redefine the USDOT portfolio of projects and evaluate the completeness of stakeholder needs. With the USDOT concurrence, the PMO updated the proposed projects and revised the PMP to reflect the changes. Additionally, the City reviewed the project advancement approach with USDOT in early November 2017. This section defines the project advancement process.

The overall SE approach is shown in Figure 3. Based on the updated project portfolio and the stakeholder needs known now, the program-level SE approach focuses on developing models of the SoS that support the following objectives to provide a:

- Mechanism that supports SoS-level technical discussions with stakeholders
- Mechanism that supports SoS-level technical discussions with the owners of external systems that interact with the SoS
- Framework that can be used to support SE activities at the individual project level

In many ways, the SoS System Breakdown Structure (SBS) is like the Work Breakdown Structure (WBS) used within the PMP. The SBS provides a hierarchically structured representation of the SoS that identifies the key components of the SoS and provides an identifiable and traceable set of nomenclature that supports the three system engineering objectives listed above. The first five steps of Figure 3 summarize the program-level SE approach; following this figure is a detailed explanation of all steps in the Smart Columbus SE approach.



Source: City of Columbus, October 2017

Figure 3. Overall System Engineering Approach

Step 1. The approach begins by collecting and reviewing existing artifacts including the draft Concept of Operations or Trade Studies associated with stakeholder elicitation and early SoS architectural concepts.

Step 2. Based on these artifacts, a top-level SBS for the SoS is drafted.

Step 3. When the SBS seems complete and stable at the SoS level, the nomenclature used for the SBS elements is scrubbed for usability, consistency, and accuracy. As part of this step, unique identifiers will be assigned to the SoS SBS elements in a manner like the assignment of unique numerical identifiers within a WBS.

Step 4. The SoS will interface with many external systems, many of which have been identified during stakeholder elicitation and early architectural planning. With the SoS SBS in place, more focus can be placed on interfaces to external systems by identifying these interfaces and the corresponding SoS SBS elements. Step 4 consists of the following activities:

a) Compile a list of all external systems that interact with the SoS; for the SoS view, the focus will be on the external systems that must interact with the SCOS. The SCOS context diagram also includes interfaces among other Smart Columbus projects, so therefore provides a robust program level view of the relationships among Smart Columbus Projects and external systems.

b) Develop a description for each external system that interacts with the SoS, including an overview of critical functionality and data available from the external system.

c) Identify the owner or sponsoring organization for each external system, and who within that organization is the point of contact (PoC) for the system both from an ownership and technical perspective (to account for both authorization and execution of any programmatic work required to establish an interface).

d) For each external system, identify the SoS SBS element that interfaces with the external system.

e) Treat each interface uniquely if an external system has an interface to more than one element of the SoS SBS. Specific interfaces (i.e., needs) for each Smart Columbus Project will be defined in the project-level ConOps. Appendix D contains a Project Evaluation Matrix, which identifies the remaining elements to be extracted and added to each document.

Step 4 identifies all SoS-level interfaces to external systems, but more importantly, it identifies the lower-level elements of the SoS which interface to external systems.

Step 5. All information will be compiled into a collection of artifacts that describe the SoS from a variety of perspectives, including a final SoS SBS and an initial SoS context diagram which models all SoS SBS elements, external systems, and interfaces. The main location for this information will be in the SoS ConOps, although additional documents such as the project-level System Requirements (SyRS) and design documents will also address interface requirements and how they will be addressed. Both program and project SE artifacts and their content are completely described later in this document in Section 5.3.1.2.

Step 6. In project-level SE documents, Steps 6 will drive requirements definition to include functional, performance, interface and other types of requirements for the individual Smart Columbus projects and their sub-components. Documenting these requirements will drive later activities related to procurement, development, integration, and test activities as needed. It should be noted that application of this SE approach at higher levels of the SBS is independent of the acquisition strategies, development methodologies, and integration approaches for the lower-level system and project elements. As the lower levels of the SBS are developed, the acquisition strategy (to include requirements development as needed), development methodology, and integration approach for each lower level element will become clearer and the lower levels of the SBS will be adjusted appropriately. For example, it is anticipated that the SBS will reflect the decomposition of extensive SoS software capabilities into many SBS software elements that could lend themselves to using an off-the-shelf software module or other integration approaches, taking into consideration available software development team resources, the software supplier base, and the Agile development methodologies. It is also anticipated that lower levels of the SBS will be structured to identify and segregate specific partner capabilities to be leveraged into SoS capabilities, and to isolate hardware and

physical infrastructure elements so that traditional SE V-Model methods can be applied to hardware development and/or hardware procurement if appropriate.

Step 7. Step 7 indicates the completion of the project-level decomposition and transition to procurement. Step 7 involves the review of the SBS to determine if it is adequate to support acquisition, development, and integration of the lower level SBS elements. Another important criterion for completion of project-level decomposition is that the requirements for the particular system thoroughly describe each system and its subcomponents, thereby sufficiently supporting a vendor partnership or request for proposal.

Step 8. Following Step 7, a complete documentation tree that aligns with the SBS will be developed (Step 8). The upper levels of the documentation tree will contain artifacts common to all projects, such as project-level ConOps, architecture, and requirements documents. Documents for the lower-level elements of the SBS will vary depending on the acquisition strategy, development methodology, and integration approach for each element.

The remainder of Chapter 3 and Chapter 4 describes the SE approach in more detail, including the process that will be used to advance the projects, presentation of the high-level SoS SBS, and more detail about specific strategies and development methodologies being considered for use during the overall SE program.

3.2.2 Scrum of Scrums

The Smart Columbus program is adopting an “Agile-type” management approach to provide regular and proactive oversight of all projects. The cornerstone of this approach is regular program-level Scrum of Scrums meetings to manage program activities. Scrum of Scrums meetings allow clusters of project teams to discuss their work, especially focusing on areas of overlap and integration. In this program, there will be nine project teams: the SCOS and one for each of the other eight projects. The project teams will include both city and Consultant staff, and vendors once under contract or partnership.

The SCOS project will be comprised of 4 to 6 Scrum teams (this will vary to meet the immediate needs of the program). Each of the other project teams will conduct their own regular project coordination meetings. These meetings will identify any blockers keeping them from delivering on their plans. V-Model project teams may hold more frequent coordination meetings to address any immediate or emerging issues. For instance, the CVE team may determine that a way to mitigate a coordination issue or a blocker with another department or entity is to hold daily scrums until the issue is mitigated. In general, though, each project team will not hold daily scrums except the SCOS team.

Each team will then designate one member of their team to serve as an Ambassador to attend the program-level Scrum of Scrums. The project team should choose its Ambassador based on who will be in the best position to understand and comment on the issues of the day. The chosen Ambassador will likely be the assigned Project Lead or City Project Manager. The Project Manager may designate an alternative representative to attend the Scrum of Scrums. If the ambassador is not the Project Lead or City Project Manager, this individual will communicate the action items to the City Project Manager to ensure commitment from the project team to complete them.

Since multiple teams comprise the SCOS project, it will have its own Scrum of Scrums meeting prior to the program meeting. The SCOS teams will conduct each of their scrums, then a representative from each SCOS scrum team will assemble to hold the SCOS Scrum of Scrums meeting. An Ambassador from the SCOS Scrum of Scrums meeting will attend the program Scrum of Scrums with each of the other V-Model project teams’ appointed Ambassadors. In that meeting the Ambassadors will identify blockers that each project team is experiencing.

The frequency for program Scrum of Scrums meetings will be semi-weekly, after the daily standup and the SCOS daily Scrum of Scrums. When there is little cross-project interaction needed, the Scrum of Scrum frequency can be reduced to weekly. Project-level daily scrum meetings last no more than fifteen minutes, as the purpose of scrums is not to solve problems. By contrast, thirty minutes will be reserved for the program Scrum of Scrums meeting, although it will often be completed in less. This allows the Scrum of Scrums to be the platform for addressing an issue that significant enough to rise to that level.

A traditional agenda for scrum meetings will have team members answer the following questions:

- What did you do yesterday?
- What will you do today?
- What obstacles are in your way or slowing you down?

Since one person represents each project team, the questions are rephrased to the following:

- What has your team done since we last met?
- What will your team do before we meet again?
- Is anything slowing your team down or getting in their way?
- Are you about to put something in another team's way?

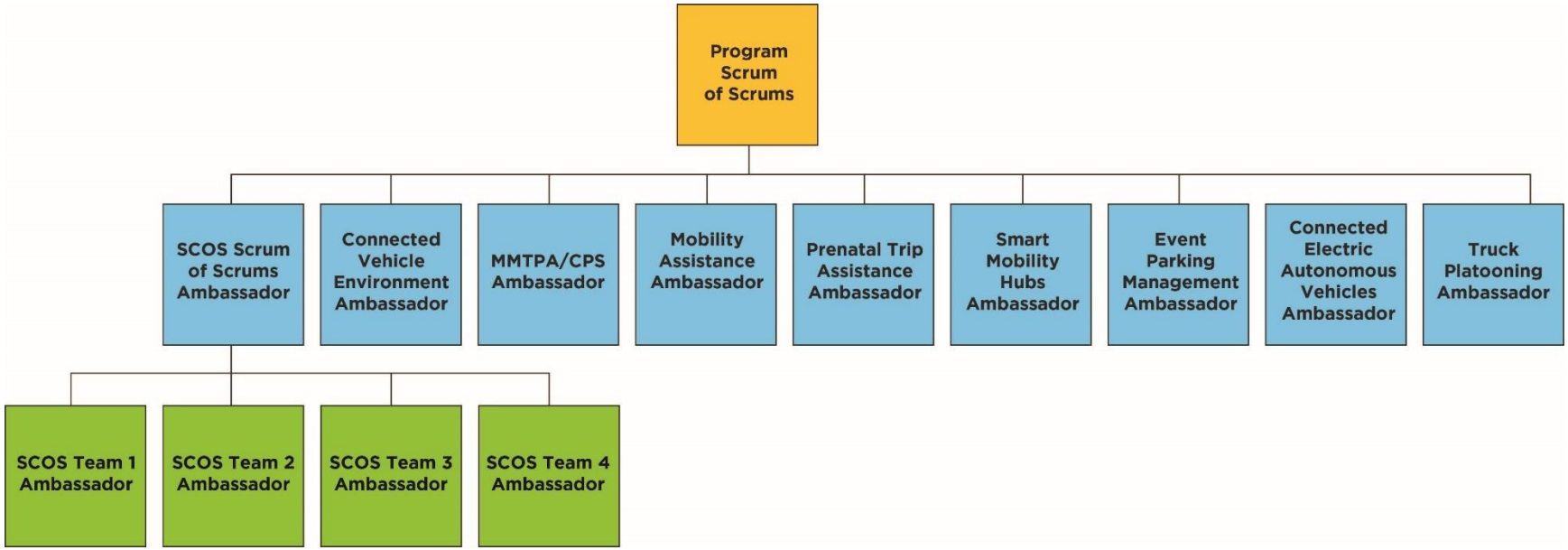
This last question is key to coordinating the work of multiple teams because having notice of potential impediments is helpful. The Scrum of Scrums meeting starts with each participant answering these four questions. Like the daily scrum, this is meant to be fast-paced and short.

After the initial questions have been answered, the focus of the meeting shifts. Participants address any issues, problems, or challenges that were raised during the initial discussion or previously identified and maintained on a program Scrum of Scrums backlog list[7] of open items. The program SharePoint site will be used to track the backlog.

While the program Scrum of Scrums meetings will maintain a backlog of issues, risks, and problems to address, they will not conduct formal iteration planning. However, retrospective meetings will be performed to identify possible process improvements that will improve the overall velocity (or rate of completion of program tasks) of the entire program. Any iteration planning and commitments that drive a project forward belong for the most part at the individual project team level. The program Scrum of Scrums team will track decisions, blockers, risks, change control, and retrospective goals that result from their meetings and actions.

An organizational chart of the current planned Smart Columbus Scrum of Scrums can be seen Figure 4 below.

[7] This backlog is a simple list of outstanding issues, response and action that participants in the Scrum of Scrums meeting either feel responsible for addressing or that they are tracking for some other reason (for example, the issue is being addressed in another meeting but this team needs to know the resolution).

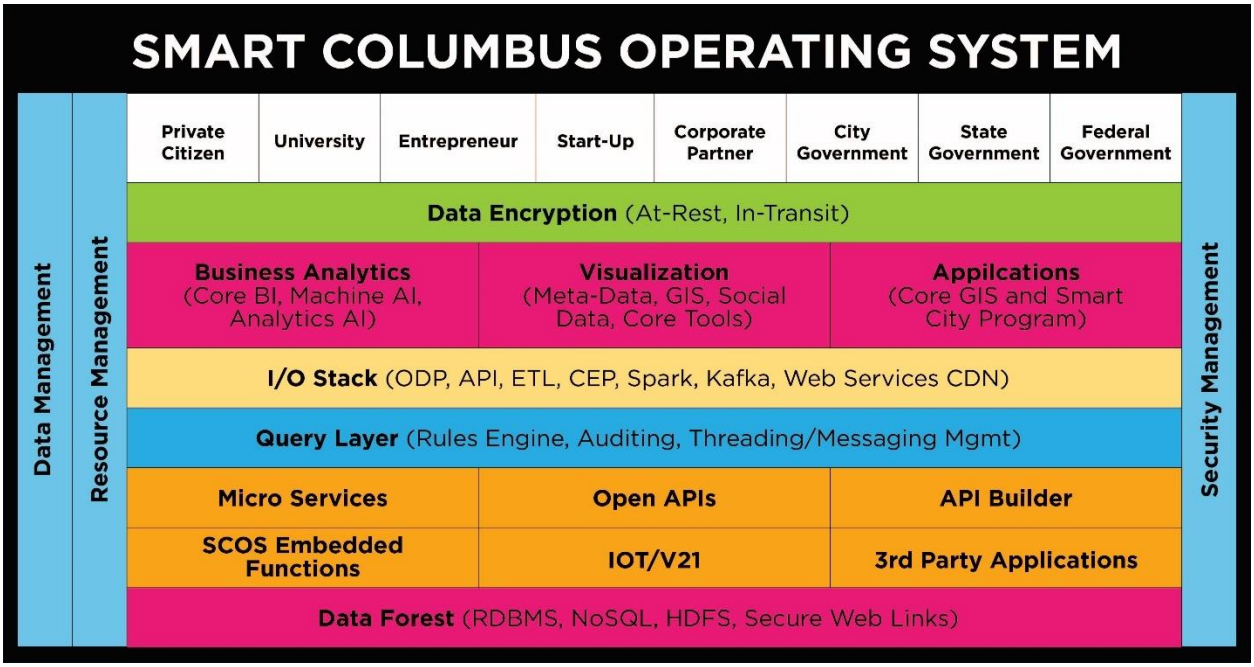


Source: City of Columbus, October 2017

Figure 4. Scrum of Scrum Teams

3.2.3 Smart Columbus Operating System (SCOS)

The SCOS is at the center of the Smart Columbus program and serves as the central data repository for all data. It will be configurable such that while certain data is a remote pass-through, other data may be permanently stored while some other data may only be held in a 24-hour buffer. These will be managed through an interface control definition and implementation process. As a point of reference, the open system interconnection diagram is shown in Figure 5; it describes the process of communications between the system endpoints. The Input/Output (I/O) – Messaging environment will be comprised of a variety of tools that will make it possible to ingest, transform and present data in many ways. The build-out and definition of the functionality will be based upon the use-cases that were developed through the ingestion process. Data tagging, being a core functionality of the SCOS is a key development component as the ability of the SCOS to tag, abstract, and store all data both structured and unstructured will be essential in providing a "management of all data" service level. Figure 5 will be expanded and further described in the SoS ConOps to completely articulate the various connections to both external systems and other Smart Columbus projects.



Source: City of Columbus, October 2017

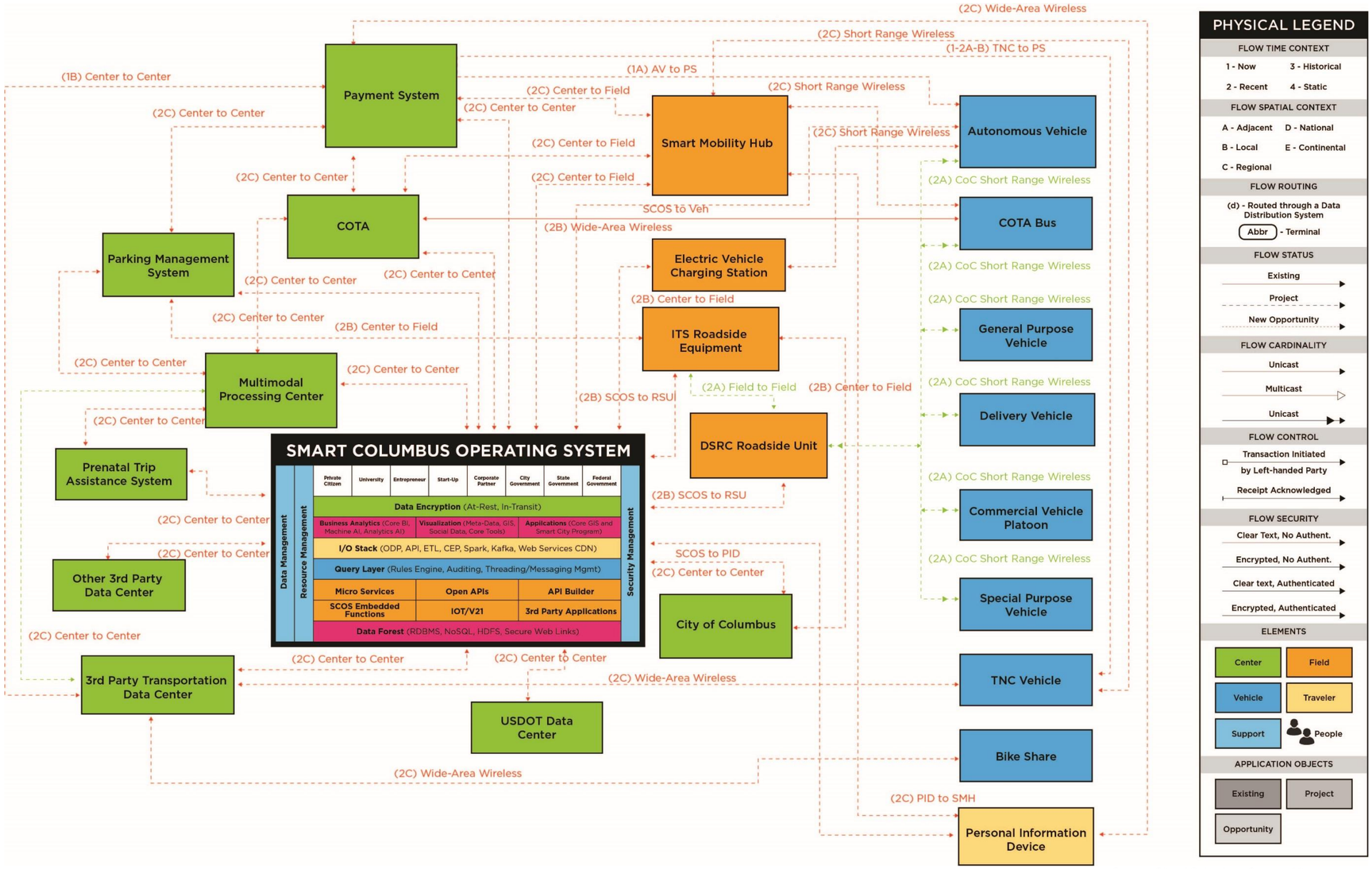
Figure 5. SCOS Open System Interconnection Diagram

The SCOS will have advanced analysis tools to include some functional Artificial Intelligence (AI) components and bots that will allow researchers to develop deep learning and 3rd party developers access to tools to use to prove their data driven solutions. There will be an environment that allows for ease of development of peripheral micro-services as well as processes for the ingestion of third party middleware into the environment that will allow applications that would otherwise be entirely separate systems to be integrated directly into the SCOS. This may positively impact the architectures of outside software components such as the MMTPA. The SCOS will be highly secure. It will adopt the most advanced security key structures for data at rest and the most reliable secure data transit environments for data in transit. Incorporating a configuration and profile-based infrastructure and user security profile

"defense in depth" processes and architectures, the development will involve integrating automated auditing and intelligent user profiling.

3.3 Program Dependencies and Integration

The key subsystem component linking all projects that make up the Smart Columbus program is the SCOS as it is responsible for functionally linking the System of System subsystem components to each other and for providing external links for USDOT evaluators and other third parties. Though most of the projects will have a computational component that is independent from the SCOS, many will utilize the SCOS as the data integration component to link to other components in the infrastructure. The projects will be decomposed into functional blocks that describe the processes that are a part of each project, as shown in Figure 6, and described in more detail in the SoS ConOps. These functional blocks will require data sources and data outputs to other functional blocks either internal to the project, external to the project, or external to the program. These project and program external data sources and outputs are the dependencies that require integration. The projects will produce an Interface Control Document (ICD) that defines the interfaces required between systems. In most cases these will consist of data exchanges, but could also be functional or performance requirements needed for interoperability between systems.



Source: City of Columbus, October 2017

Figure 6. Smart Columbus Program-Level Context Diagram

3.4 Project-Level System Engineering Approach

At the project level, all the projects except for the SCOS will begin with the standard V-Model approach. Following this process will enable the definition of each project concept, user needs, and system requirements. Currently, the team has begun the process of defining the concept and user needs. Following the program reset in September 2017, the PMO and project teams will gather the remaining user needs and capabilities, document them in the final ConOps and Trade Study documents, and then define and produce systems requirements documents. These requirements will be derived by breaking down the system's requirements (functional, performance, data, security, interface, etc.) reflected in the ConOps and Trade Studies and vendor systems. The system's requirements will be defined at a sufficient level to provide viable procurement documents and identify the necessary interfaces. The requirements will also serve to generate the Requirement Verification Traceability Matrix (RVTM) to be used for acceptance of the vendor product. An example RVTM is in Appendix C. The SyRS for ConOps projects (and Interface Control Documents, ICD, for Trade Study projects) will be a key element in the request for proposals (RFP) for vendor solutions, whether the solution is off-the-shelf or customized.

The vendor may choose to deliver the product in stages through an Agile methodology or a standard V-Model approach. The vendor will deliver all known requirements as specified in their request for proposal; however, the given that some of the projects will be deploying technology which rapidly evolves, vendor contracts will include provisions for emerging requirements to be included post-deployment. In addition, user-facing software products may have release updates that occur post-deployment. This calls for V-Model projects to "pivot to Agile" to implement further iterations until agreed upon requirements are met. This should not be considered a scope change, but should be planned in to the deployment methodology. In the case that a project does pivot to Agile after vendor selection, the required deliverables would then be aligned with Agile artifacts.

Specific project-level deliverables associated with the V-Model and Agile processes are described in Chapter 5. In the case of a vendor-provided solution, content and inputs for these deliverables would be specified in their contract, although the Project Teams would be ultimately responsible for delivery to USDOT. For projects that pivot to Agile, V-Model deliverables will be prepared as the project development progresses; once the decision is made to pivot, the Agile process will then take precedent. Agile process deliverables will be prepared, beginning with the product vision and continuing through user story definition and development.

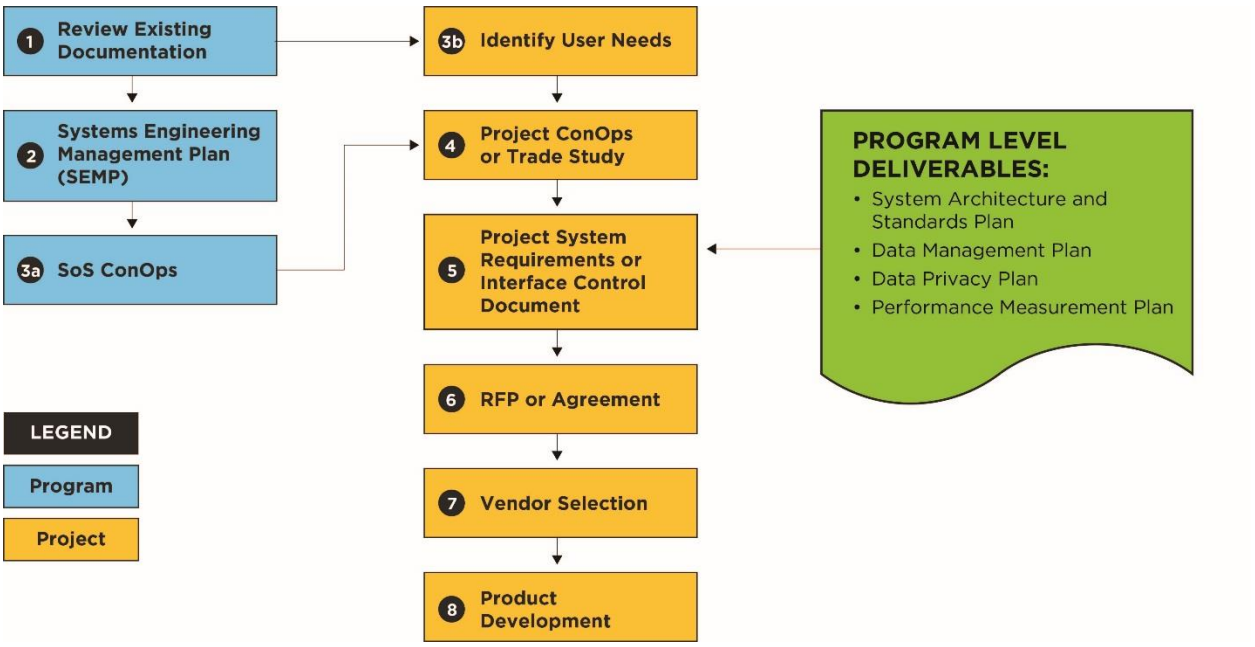
3.4.1 Project Advancement Approach

The PMO will evaluate each project individually to determine the appropriate development approach (V-Model or Agile) to completing its design, testing, and deployment. As noted in Section 3.4 above, some projects may begin using the V-Model approach and then transition to an Agile methodology to complete design, testing and deployment – this is described in more depth in Section 4.1.3, while the criteria for what approach is most appropriate are documented later in this document (Section 4.2). The documentation that is required for each approach is described in Chapter 5.

The core SCOS is being built by city staff and consultants using the Agile development methodology, and will therefore not be evaluated using this approach. For the remaining eight projects, the City has documented each project's outcomes, objectives, and user needs with draft ConOps and Trade Studies. This documentation will be used to initiate the approach outlined in Figure 7. The approach is intended to leverage the work completed to date if appropriate and define the path forward. It moves from the assessment of these materials through the next steps of documenting the project requirements and soliciting vendor responses

regarding the concept and design development for their delivery. The status of the work completed for each project and the remaining items to be added is defined in Section 3.4.2 and Appendix D.

Initial definition of the project advancement approach and how the planned documentation will support it is outlined below, and captured graphically in Figure 7. This figure includes the initial steps to be taken to advance the project – this is the work that the project team will complete in concert with the project ConOps/Trade Studies and SyRS. It describes the specific steps to drive the project team to vendor selection and implementation; it is not intended to capture the latter steps identified by the V-Model or Agile processes (reference Figures 8 and 9 in Chapter 4). Depending on the development approach selected by the City, the project will then continue with the relevant process (V-Model or Agile) and required deliverables as indicated in Chapter 5.



Source: City of Columbus, October 2017

Figure 7. Project Advancement Process

Specific activities related to each element of Figure 7 are included in Table 4.

Table 4. Description of Project Advancement Steps

Step	Activities
1: Review existing documentation	• Evaluate the work completed to date (draft ConOps and Trade Studies) • Score the readiness of each project (1-5 scale) • Identify steps to finalize ConOps and Trade Studies
2: Systems Engineering Management Plan	• Develop program level SBS and update the SEMP. The SEMP will be referenced and provide guidance to the project team's as they complete their ConOps or Trade Studies.

Step	Activities
3a. SoS ConOps	• Create an overarching ConOps document which defines the relationship and interactions of the SCOS and the other projects. This step runs concurrently with Identify User Needs, although it will be completed prior to the project-level user needs.
3b. Identify User Needs	• Review the user needs and engage users to ensure essential and desired needs are captured or validated. This step runs concurrently with the SoS ConOps, although it will be finished after the draft SoS ConOps is submitted.
4. Project ConOps or Trade Study	• Incorporate user needs and finalize ConOps or Trade Study
5. Project System Requirements (ConOps projects) or Interface Control Document (Trade Studies)	• Document project and program requirements (ConOps) or interfaces (Trade Studies) and establish traceability to project user needs. The SyRS or ICD will be the foundation for the request for proposal (if the RFP will be competed among multiple vendors); if the capabilities will be provided by a partner through an agreement, a draft ICD should be prepared before an agreement is finalized. Each project's requirements will vary, in general, the following documents will be incorporated into the SyRS and ICD: system architecture and standards plan, data management plan, data privacy plan, performance measurement plan, etc.
6. Request for Proposal (RFP)	• Develop an RFP based upon the earlier documentation for each project (ConOps or Trade Study, SyRS or ICD). Note, for project capabilities that will developed and delivered by a partner, a final agreement would replace the RFP.
7. Vendor Selection (Decision)	• Review responses and determine the best value based upon technical and cost based merits. • Responses will be evaluated based upon their satisfaction of SyRS or ICD and their approach to doing so. • Note that vendor selection does not apply for projects that delivered by a program partner (under an agreement).
8. Product Development	• Work collaboratively with the selected vendor to ensure scope, schedule, and budget are met. Ensure documents required by the USDOT Cooperative Agreement are completed.

After Step 7 is complete, the City will be actively engaged in the vendor's project management and become a key stakeholder and decision-maker in their process. The vendor will have representation in the program Scrum of Scrums meetings to report status, identify any blockers to other projects, and listen for blockers from other projects to their efforts. The SCOS team will coordinate user stories related to the integration of individual projects with the SCOS. This coordination will occur through the SCOS's existing Agile development process.

The SEMP will be updated to include the definition of each project's system breakdown structure, align with the PMP, and document the deliverables for each project.

3.4.2 Project Advancement Initiation (ConOps, User Needs, Trade Studies)

As discussed in Section 3.2, the PMO is using an overarching Agile-type approach to manage the program as the City moves forward. The City IT PM will provide leadership over the program Scrum of Scrums process and ensure there is consistency between the program and project-level scrums. To continue the advancement of each project, the PMO is analyzing all the user needs gathered during the preparation of the ConOps and Trade Studies, and have documented USDOT-accepted project advancement initiation points (shown in Project Evaluation Matrix in Appendix D). Initiation points are the starting point to managing the program using the Scrum of Scrums approach.

Each of the eight projects and their documentation will be reviewed and scored on a scale of one to five. The scoring scale is presented in Table 5. It is intended to help the project teams assess how complete their user needs are and identify the next steps to finalizing the user needs and their documentation (whether it is in a ConOps or Trade Study).

Table 5. Project Evaluation Criteria

Score	Criteria
1	Missing a lot of critical information; a lot more discovery work to do
2	Have some information, most critical information is gathered, need more discovery meetings with end-users and stakeholders to complete the picture
3	Have a lot of information collected but have some work to do to complete the picture; including additional meetings with stakeholders.
4	Document for USDOT Acceptance (i.e. ConOps, Trade Study) in decent shape - based on last review / comments from USDOT but does require some modifications. No additional meetings required with stakeholders for additional needs.
5	Document for USDOT Acceptance (i.e. ConOps, Trade Study) in good shape - based on last review / comments from USDOT; minor modifications. No additional meetings required with end-users for additional needs.

The DPgM (Technology) will coordinate a meeting with the City PMs, Project Leads and Systems Engineer to review each project. The agenda for this meeting is as follows:

- Review each project's documentation:
  - Stakeholders
    - Review identified stakeholders and end users
  - User Needs
    - How were they gathered?
    - Are there stakeholders we need to go back to?

    - Is there traceability of stakeholder's needs?
- Outcomes:
    - Identify gaps (needs analysis)
    - Establish readiness for traceability for stakeholder engagement
    - Inventory of documentation and its support to traceability
    - Identify gaps (needs analysis)
    - Determine scope of document update
    - Prepare an evaluation score (readiness level)
- Next Steps:
    - Complete stakeholder engagement
    - Fully document user needs
    - Establish traceability
    - Finalize USDOT deliverables

The project evaluations were conducted in November 2017, the results were summarized in a matrix format for quick reference to the project team and for communication of results to USDOT. This matrix has been discussed and accepted by USDOT. This matrix will not be a formal deliverable, but rather a snapshot of the project evaluation process. An initial accepted matrix is presented in Appendix D, and the summary of scores and deliverables by projects is below in Table 6 .

Table 6. Summary of Project Evaluations

Project	Score	Deliverable
CVE	4	ConOps
MMTPA/CPS	3	ConOps
Smart Mobility Hubs	1	ConOps
Mobility Assistance	5	Trade Study
Prenatal Trip Assistance	1	To be determined (TBD)
Event Parking Management	2	ConOps
CEAV	2	ConOps
Truck Platooning	4	Trade Study

3.4.3 Acquisition Evaluation Factors

In executing the vendor selection for each project, the ability to meet the system requirements will serve as the primary evaluation factor. A requirements matrix will be used to document the ability of a product to meet or exceed requirements. Technical evaluation criteria for project proposals will be determined on a project by project basis, but will include the vendor's response to each requirement in the SyRS. In addition to the specific assessment of the SyRS generated for each project, some of the high-level technical criteria may include:

- Type and definition of architecture
- Level of integration required
- Operational readiness of available products
- Definition of interfaces
- Product flexibility to meet changing demands
- Vendor's cost contribution

In addition, City of Columbus Department of Public Service standard criteria for evaluating vendor responses will be considered. These criteria are typically weighted by importance, and will include:

- Project manager experience and availability
- Past performance on similar projects
- Understanding of project and approach
- Location of solution provider and resources
- Price

Chapter 4. Systems Engineering Processes

The SE process will be initiated based on the Project Advancement Approach described in Section 3.4. The SCOS is a highly interactive project touching all the other projects. Therefore, it will be developed using an Agile process. Some of the other projects will utilize the V-Model approach to complete concept definition, user needs gathering and requirements development to drive the project teams to the point of vendor selection. Finally, a few projects will utilize a complete or near-complete solution; for these projects, the V-Model will not be followed explicitly given that the solution does not require a complete design and build effort to deploy. These projects will begin by documenting the capabilities of the available solutions in a Trade Study.

Regardless of whether the remaining projects follow the traditional V-Model process or Trade Study path, the processes utilized to deploy each project following vendor selection will be evaluated to determine the most appropriate means of moving forward. This chapter describes each process, as well as guidance for selecting the appropriate process based on project objectives and attributes.

4.1 Development Methodology

4.1.1 V-Model

This section describes the process the City will utilize to implement V-Model practices within a development methodology. This section also defines the methodology and provides an overall direction for both development and oversight activities.

The V-Model process should be considered when:

- The project will deliver products on the critical path.
- The project will deliver products with Safety-of-Life functionality.
- The project will deliver products requiring operations and maintenance (O&M) support beyond the life of the Smart Columbus program.
- The project will benefit from prioritizing detailed product definition over speed of development.
- The development team has previous experience with Waterfall (i.e. V-Model) development processes.

4.1.1.1 Definition

V-Model is a sequential system development process in which progress flows steadily in a straight line, or downward, through life cycle phase of conception, development, production, utilization, support, and retirement. The City will utilize the Federal Highway Administration (FHWA) Systems Engineering for Intelligent Transportation Systems Guide as guidance for this process. If gaps are identified in the FHWA guide or additional detail is required, the City will refer to the INCOSE Systems Engineering Handbook, Fourth Edition.

4.1.1.2 Roles and Responsibilities

The City has identified project-level specific roles and responsibilities necessary to implement Smart Columbus V-Model managed projects. Key roles and responsibilities are listed in Table 7.

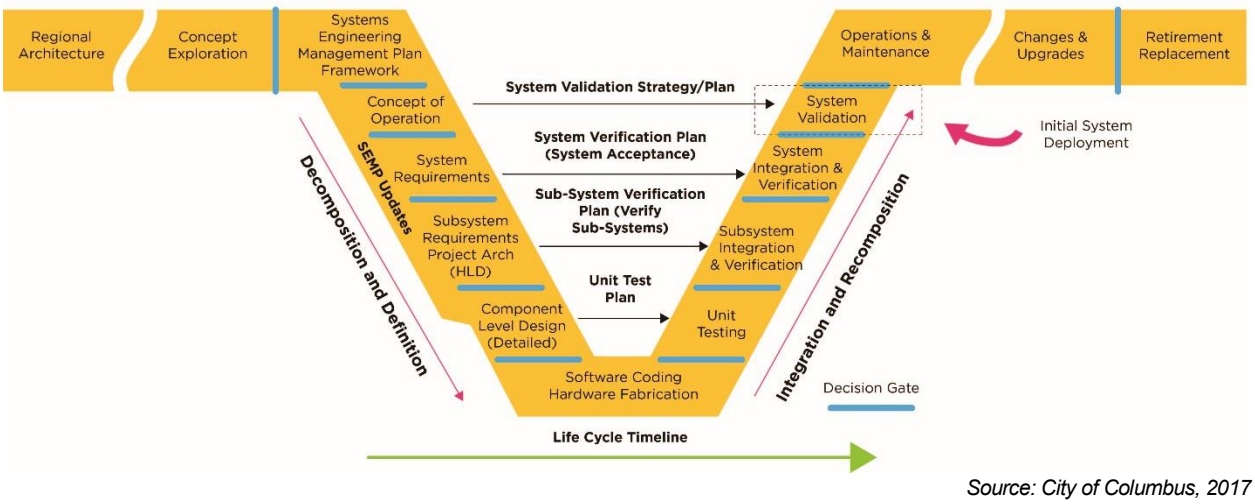
Table 7. V-Model Key Roles and Responsibilities

Role	Description	Smart Columbus Considerations
PgM	The Program Owner has overall responsibility for the entire program, providing oversight and direction to individual project teams	For Smart Columbus, the City of Columbus, Department of Public Service will be the program owner
Business Owner	The business owner is the cornerstone of project success, responsible for defining the work that needs to be completed and prioritizing that work. The individual needs to understand what the project is expected to deliver and why particular elements are important. The business owner must find a result that will satisfy the stakeholders' needs and desires. The business owner provides direction and goals for the team, and prioritizes what will be done.	The City of Columbus is the owner of software and hardware developed and deployed to support the program. Individual city departments and COTA will act as project business owners.
Project Lead	The Project Lead has overall responsibility for delivering a project to the business owner.	A consultant team Project Lead is assigned to each project.
Lead Systems Engineer	The Lead Systems Engineer provides oversight for the engineering processes, guiding projects through the process, answering questions, improving the processes, and updating and distributing process documents.	The Lead Systems Engineer will have overall responsibility for the Smart Columbus engineering processes with ITS and Systems Engineers supporting individual projects.

Role	Description	Smart Columbus Considerations
Technical Team	Typical V-Model teams will consist of a Project Lead, Systems Engineer, software developers, if required, IT personnel, if required, installation personnel, and personnel for other specialties as required. The Systems Engineer will conduct verification and validation. The team acts collectively to determine how to achieve their goals. The business owner will set the priority for specific features.	Each Project Lead will ensure technical reviews are ready prior to business owner review/engagement and advise the business owner on project progress and assist in providing status updates to the program owner.
Stakeholders	The development team is providing the solution(s) for the stakeholders' desires, wants, and needs.	At the outset of development, the program owner, business owner and Project Lead will identify a list of stakeholders. It is expected that this list will evolve during long duration development efforts. The business owner will decide when to add or remove involvement from given stakeholder(s).

4.1.1.3 Workflow

Smart Columbus will utilize the V-Model Process as defined in the FHWA Systems Engineering for Intelligent Transportation Systems Guide and illustrated in Figure 8.



Source: City of Columbus, 2017

Figure 8. V-Diagram

FHWA added “wings” to the original V-Diagram to better support ITS project life cycles. The left wing captures initial project identification and scoping based on regional needs. The City of Columbus is part of the Central Ohio Regional Architecture. In the event updates are required to the Regional Architecture, the program owner will coordinate with the Mid-Ohio Regional Planning Commission (MORPC) to update the architecture. The program owner will also coordinate the USDOT Connected Vehicle Reference Implementation Architecture (CVRIA) team to update the CVRIA based on Smart Columbus.

The right wing captures the operations and maintenance, system modifications and updates, and system retirement/replacement. The left and right wings were added to represent the entire life cycle during development.

In the Decomposition and Definition phase (Feasibility through Detailed Design), user needs are captured and an overall ConOps defined. User needs are then transformed into System Requirements that define what the system will do. The process by which this occurs begins with the project-level SBS – as articulated earlier in Section 3.2.1, specifically Figure 3 Steps 6-7. Breaking down the system into its components and sub-components will drive requirements definition to include functional, performance, interface and other types of requirements. These requirements drive later activities related to procurement, development, integration, and test activities as needed. It is anticipated that project-level SBS will be structured to identify and segregate specific partner capabilities to be leveraged into SoS capabilities, and to isolate hardware and physical infrastructure elements so that traditional SE V-Model methods can be applied to hardware development and/or hardware procurement if appropriate.

Lastly, a System Design is developed based on the Requirements. Once the design is complete, individual field, vehicle, and back office components are developed and deployed and prepared for testing in the Implementation phase.

During the Integration and Recomposition phase (Unit/Device Testing through Changes and Updates), system components are first tested and evaluated individually and then as a complete system. Testing includes both validating the system addresses the User Needs and overall Concept of Operation and verifying the system meets the defined requirements. The Integration and Recomposition Phase (the right “wing” of the V-Model) is intended to mirror and provide the tools to validate the concept, requirements and design elements generated by the SBS and documented in the left “wing” of the V-Model.

4.1.1.4 Programmatic Interface

It is the responsibility of the Lead Systems Engineer to coordinate with the project team (PMs and Project Leads) and the City to increase the transparency of the artifacts. To balance the program’s priorities with the priorities of individual projects, the PMs, Consultant PgM, Lead Systems Engineer, and business owners will work together to ensure program level stakeholders are involved incrementally as project stakeholders. This will allow at least monthly input from the stakeholders through the business owner to how well the project documents capture and address user needs and the overall program priorities.

4.1.1.5 Process Updates

In the event a project team has questions concerning certain aspects of the V-Model process described in this section, they should contact the PM and Lead Systems Engineer. The Lead Systems Engineer will collaborate with the Project Lead to resolve the question. If it is determined that an update to the process or clarification is required in the SEMP, the Lead Systems Engineer will develop and submit recommendations to the PM, PgM, Consultant PM, and DPgMs. Once the recommendations are approved, the Lead Systems Engineer will update the document accordingly and publish the update on the SharePoint site. Updates will also be communicated during weekly program calls between the PMs, Project Leads, and the project staff.

4.1.1.6 References

This section contains links to references discussed for the V-Model Process as well as other points of reference that could be helpful when developing a project utilizing the V-Model approach.

- INCOSE Systems Engineering Handbook: http://www.incose.org/ProductsPublications/sehandbook
- FHWA Publications: http://www.ops.fhwa.dot.gov/publications/publications.htm
- FHWA Systems Engineering for Intelligent Transportation Systems: http://www.ops.fhwa.dot.gov/publications/seitsguide/seguide.pdf
- ISO/IEC/IEEE 15288 Systems and software engineering -- System life cycle processes: http://www.iso.org/iso/catalogue_detail?csnumber=43564
- Project Performance International Systems Engineering Key Downloads: http://www.ppi-int.com/systems-engineering/downloads.php

4.1.2 Agile

This section describes the process in which the City will implement Agile practices within a development methodology. This section defines the methodology and provides an overall direction for development and oversight activities. Additionally, the City will continually assess the process for continuous improvement as well as evaluate other process alternatives if a selected development team is more inclined to other Agile based development methodologies.

The Agile process should be considered when:

- The product can deliver partial operation functionality or capability over time, with interaction
- The product owner or customer will be actively involved in the development process
- The product will benefit from high degree of flexibility to understand and meet project owner or customer objectives
- The development team has previous experience with iterative development processes

4.1.2.1 Definition

While Agile principles support a range of software development approaches, the City will utilize a scrum development process[8,9] to drive Agile development efforts on the program. Scrum is an Agile team-based process guided by individuals and interactions over processes and tools, working software over comprehensive documentation, customer collaboration over contract negotiation and responding to change over following a plan. Scrum relies on a self-organizing and cross-functional team working together to address complex adaptive problems, while productively and creatively delivering products of the highest possible value through an iterative series of development sprints[10] and resulting incremental product releases.

[8] The Scrum Guide™
[9] https://www.scrumalliance.org/agile-resources/scrum-roles-demystified
[10] A sprint is a regular, recurring work cycle

4.1.2.2 Roles and Responsibilities

The City has identified project-level specific roles and responsibilities necessary to implement Smart Columbus Agile Scrum managed projects. Key roles and responsibilities are listed in Table 8.

Table 8. Scrum Key Roles and Responsibilities

Role	Description	Smart Columbus Considerations
PgM	The PgM has overall responsibility for the entire program, providing oversight and direction to individual project Teams.	The City's Department of Public Services will be the Program Owner.
DPgM (Technology)	The DPgm (Technology) is backup to the PgM and directly oversees the SCOS efforts and integration initiatives between projects including Scrum of Scrums approach. The DPgM is also responsible for providing guidance and support around Agile methodologies.	The City's Department of Public Services will be the Program Owner.
Product Owner/ Manager	The product owner is the cornerstone of project success, responsible for defining the work that needs to be completed and prioritizing that work. The individual needs to understand what the project is expected to deliver and why particular elements are important. The product owner must find a result that will satisfy the stakeholders' needs and desires. The product owner provides direction and goals for the Team, and prioritizes what will be done[11] . The product owner participates in daily scrum meetings throughout each Sprint.	The City of Columbus is the owner of software and hardware developed and deployed to support the program. Individual city departments will act as product owners for projects relevant to their department.

[11] https://www.scrumalliance.org/community/articles/2009/december/scrum-in-a-nutshell#sthash.6bgLIDHf.dpuf

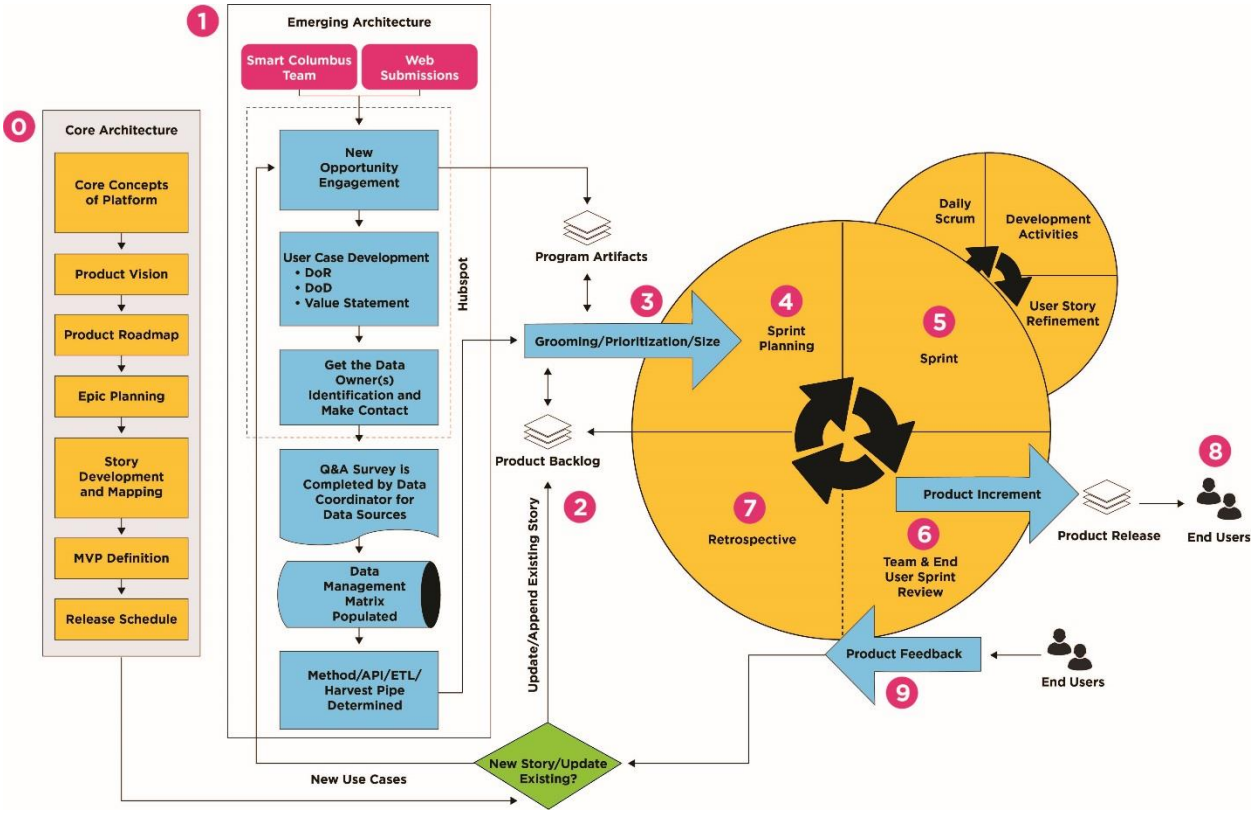
Role	Description	Smart Columbus Considerations
Scrum Master	The Scrum Master role has two distinct elements. First, the individual acts as the protector of the team, making sure that everyone on the project, especially the development team members, can focus on their work without any distractions. Some of those distractions may be directly associated with the work -- the product owner who oversteps the boundaries, for example, and starts to dictate the work approach to the team. The Scrum Master may need to protect the team from organizational disruptions or internal distractions. The second element of the Scrum Master role is to protect the Scrum process itself. The Scrum Master is the expert on how Scrum works and how it should be applied and will ensure that the product owner and development team stay within the Scrum process. By extension, the Scrum Master can coach the other team members on how to use Scrum in the most effective manner.	The PMO has designated a Scrum Master.
Scrum Team	A typical Scrum team consists of five to nine people and generally includes the typical functional roles required to complete the project. In software development, that means architects, testers, developers, and designers; but those titles are only relevant in establishing everyone's expertise. The team acts collectively to determine how to achieve their goals. The features they work on are determined by the priority established by the product owner. The way they work is guided by the Scrum process, as monitored by the Scrum Master. Everything else is up to the team to manage, with the Scrum Master providing as much support as needed to allow that to happen. For example, each team member can take a feature from the prioritized product backlog, then decide individually how to execute that work.	Each Project Lead will ensure technical reviews are ready prior to product owner review and engagement, and advise the product owner on project progress and assist in providing status updates to the program owner.
Stakeholders	The most important role involved in Scrum is the stakeholder, as the stakeholders are the ones who have desires, wants, and needs, and are the reason the team is developing the	At the outset of development, the program owner, product owner and Project Lead will identify a list of stakeholders.

Role	Description	Smart Columbus Considerations
	software in the first place.	It is expected that this list will evolve during long duration development efforts. The product owner will decide when to add or remove involvement from given stakeholder(s).

4.1.2.3 Workflow

Many of the Smart Columbus resources (city employees and consultants) currently practice iterative development activities. The following workflow is presented to encourage consistency of practice and terminology use throughout all Smart Columbus Agile projects. This is important due to the number of stakeholders involved as well as the reporting requirements of the program.

Figure 9 illustrates the Workflow with the workflows stages further described in Table 9.



Source: City of Columbus, October 2017

Figure 9. Smart Columbus Scrum Software Development Workflow

Table 9. Description of Workflow Stages

Stage	Description
0	The build out of the core ideas and concepts of the program are defined. The product vision is set then published into the program roadmap. The roadmap is broken down into major categories called Epics. The Epics are prioritized and broken down into stories. These stories are focused upon establishing the core operational infrastructure. These stories are prioritized with the use-case stories through a prioritization step, then moved to the backlog.
1	As the roadmap is being built and after the minimal viable product (MVP) is fully developed the use case ingestion process will be continuously cycled to coordinate the ingestion of use cases that will iteratively help to define the design and priority of the development of the functional architecture of the system. This process is managed using a customer relationship management (CRM) tool to coordinate the tracking and workflow of a use case. As the data curator engages upon a new use case, all the contact information is taken. A value statement is created along with a definition of ready (what needs to be in place to develop the solution) and a definition of done (how are we going to test the system to know it meets the needs) a questionnaire is distributed then a data matrix is compiled. The technology team decides upon the method of development and creates stories that will result in a deliverable.
2	The product owner, Scrum Master, stakeholders and development team prepare the user stories laying out the building blocks for development that will be the product backlog.
3	Stories are prioritized by the product owner in a process called grooming. The development team sizes each item and seeks clarification from the product owner.
4	The development team chooses the number of stories to add to the Sprint based on the priority assigned, effort needed and past Sprint performance.
5	The development team focuses upon delivering their stories, having 15-minute daily Scrums and completing the backlog items to the Definition of Done as defined by the user stories.
6	The development team formally presents all the items they have completed to the product owner and stakeholders. Feedback is gathered and processed accordingly.
7	Upon finishing each Sprint, the Scrum Team discusses what went well, what did not, and what to improve in an event called a retrospective. These are tracked for remediation.
8	Work accepted by the product owner and stakeholders can be deployed to production. Each Sprint is a potentially shippable increment of software.
9	Bugs and small changes are added to the current Sprint. Other requests are added to the backlog if approved by the product owner.

4.1.2.4 Programmatic Interface

It is the Scrum Master's responsibility to work with the team and the City to increase the transparency of the artifacts. To balance the program's priorities with the priorities of individual projects, the Scrum Master and respective product owners will work together to ensure program-level stakeholders are involved incrementally as project stakeholders. This will allow at least monthly input from the product owner to how sprint backlog priorities fit into the overall program's priorities.

4.1.2.5 Process Updates

In the event a project team has questions concerning certain aspects of the Agile process described in this section, they should contact the Scrum Master and Lead Systems Engineer. The Scrum Master and Lead Systems Engineer will collaborate with the project team to resolve the question. If it is determined that an update to the process or clarification is required in the SEMP, the Scrum Master and Lead Systems Engineer will develop and submit recommendations to the PgM and product owner. Once the recommendations are approved, the Lead Systems Engineer will update the document accordingly and publish the update on the SharePoint site. Updates will also be communicated during weekly program calls between the PMs, Project Leads, and the Lead Systems Engineer.

4.1.2.6 References

This section contains information and resources used in the documentation of the Agile process and can serve as resources to the overall Smart Columbus program team.

- The Scrum Guide™: http://www.scrumguides.org/docs/scrumguide/v1/scrum-guide-us.pdf
- http://www.innolution.com/val/modal/when-grooming-happens
- https://www.scrumalliance.org/agile-resources/scrum-roles-demystified
- https://www.scrumalliance.org/community/articles/2009/december/scrum-in-a-nutshell#sthash.6bgLIDHf.dpuf
- https://www.pivotaltracker.com/blog/guidelines-for-mastering-agile-development-with-tracker/
- https://www.scrumalliance.org/community/articles/2013/september/agile-user-stories
- https://www.scrumalliance.org/community/articles/2016/october/a-template-for-easy-scrum-retrospective-preparatio
- https://www.scrumalliance.org/community/articles/2008/september/definition-of-done-a-reference

4.1.3 Existing Solutions

Some of the City's partners will provide complete or near complete end-to-end solutions to satisfy project goals and objectives. These solutions will be treated as existing solutions that may not require complete design and build efforts. Yet they will need to be integrated into the SCOS, to other Smart Columbus projects and to external/3rd party systems. For these projects, the project team will prepare a trade study to identify the most balanced technical solutions among a set of proposed viable solutions.[12] Since established solutions are available and their requirements, capabilities and design well established, the V-

[12] Federal Aviation Administration (2006).

Model process is not followed. Specifically, certain V-Model documents are not required, including the SyRS and System Design Document. For projects using an existing solution, the project advancement process documented in Figure 6 will still be followed, with the Trade Study replacing the ConOps, and an ICD replacing a complete set of SyRS. The ICD provides the specific requirements to integrate the existing solution into the Smart Columbus program and ensures the selected vendor can satisfy these requirements. A partnership agreement should not be finalized until a draft ICD has been prepared and reviewed by USDOT.

4.1.4 V – Pivot to Agile

While the projects will begin with the normal V-Model through the procurement of the vendor system, the vendor may choose to develop and implement the system in an Agile process. This has the advantage to be able to deliver initial capability quickly and then work to deliver the complete functionality in an iterative process. It is also anticipated that the nature of the emerging technologies being deployed and the feedback that will be generated after initial deployment will require additional or modified requirements to be implemented. Therefore, a project that begins as a V-Model deployment may transition to an Agile process. This will especially be the case with software products. There is usually a requirement to maintain software versions that adapt to new operating systems, operating hardware, and new functionality.

The decision to pivot to an Agile process will be made collaboratively between the PgM, city PM, Consultant Project Lead and Vendor. The criteria for transitioning to the Agile methodology is dependent on the readiness of the vendor product and its ability to deliver functionality in stages. For example, a minimum set of high priority functionality is ready for deployment while custom and/or emerging requirements may require additional development. The Agile process supports the incremental development and deployment of the overall functionality, allowing the projects to be deployed sooner while full functionality is developed. Once a project pivots to the Agile process, the vendor will participate in the scrum process as documented in Figure 9, working as a member of the project team to identify opportunities, prepare/groom/prioritize user stories, and deliver product increments. The vendor's key role will be to serve as the development team to execute all sprints (participating in the daily scrum calls, leading and executing all development activities and refining user stories as needed). The vendor will also participate in the development of Agile artifacts as documented in Chapter 5.

4.2 Considerations For Adopting V-Model or Agile Methodology

The SE approach for Smart Columbus must be flexible to accommodate the evolving requirements of this innovative demonstration program. To plan and execute the most effective overall SE program, the SE approach allows for the use of both Agile software development methods and traditional SE V-Model developments, depending on the functionality being developed. The following discussion describes the factors to consider when selecting a development methodology.

The V-Model methodology originated in the military community during the mid-twentieth century where, prior to the information age, acquisitions of military equipment typically had long lead times and significant, time-consuming, costly rework if delivered systems could not meet the military's system requirements. During the information age, Agile emerged as an alternative to the V-Model to take

advantage of the fact that many IT systems are not shackled with the risks associated with the acquisition of hardware intensive systems and their long lead times. Consistent with this history, the INCOSE characterizes the V-Model versus Agile development methodologies as being predictive versus adaptive. The above history and the INCOSE characterization describe the starting point for the V-Model versus Agile development methodology selection criteria within the Smart City SE approach.

From the SE and program management perspectives, both the V-Model and Agile development methodologies have costs and benefits which have been extensively discussed in the literature. Because the program is a software-intensive demonstration program, the bias is towards the more adaptive Agile development methodologies and towards projects where Agile can be leveraged to eliminate slack. There will be cases however where a V-Model development methodology is appropriate. In the Smart Columbus SE approach, there are two primary considerations for assessing the use of V-Model versus Agile:

Table 10. Primary Considerations for Assessing V-Model vs Agile Development Methodologies

Initial versus Incremental	If the capability to be developed is incremental to an existing capability, the Agile development methodology may be more appropriate than V-Model. However, if the capability is starting from scratch and is large, V-Model may be more appropriate. Note that SE techniques can be applied to decompose large capabilities into smaller elements that can then be individually assessed for the use of V-Model or Agile.
Software versus Hardware	If the capability to be developed involves no long lead time hardware, the Agile development methodology may be more appropriate than V-Model. If the capability includes long lead time hardware, V-Model may be more appropriate. Note that SE techniques can be applied to decompose capabilities that include hardware into separate hardware and software elements that can then be individually assessed for the use of V-Model or Agile. This decomposition process also aids in the identification of off-the-shelf hardware which, once identified, can be procured using normal procurement processes, where no development is required. Given advances in technology, using Platforms as a Service offers an alternative to long lead hardware IT procurement cycles. This alternative can be leveraged to expedite software development while permanent IT hardware is sourced, allowing Agile to be utilized where once only V-Model could be considered.

These considerations will be used as the primary development methodology selection criteria within the SE approach. As projects and project architectures are decomposed as part of refining acquisition approaches, the above primary considerations can be applied to the lower-level components resulting from the decomposition.

When selection of V-Model or Agile using the above criteria is not clear cut, additional factors will be considered. Table 11 (adapted from "*Defense Agile Acquisition Guide*", The MITRE Corporation, March 2014) provides a preliminary set of criteria that may be used when "Initial versus Incremental" and "Software versus Hardware" alone are not adequate to make a V-Model versus Agile choice.

Table 11. Detailed Consideration for Assessing V-Model vs Agile Development Methodologies

Assessment Area	Consider Agile practices if	Consider V-Model practices if
Requirements Stability	Requirements cannot be well defined or baselined upfront.	Requirements have been relatively well defined upfront.

Assessment Area	Consider Agile practices if	Consider V-Model practices if
Requirements Divisibility	Requirements can be decomposed on-the-fly to support iterative development. Risk is managed through scope refinement.	Requirements must be decomposed up front to reduce development risk.
User Timelines	Users welcome iterative development and desire/require frequent capability upgrades.	The user environment does not allow iterative development or lacks the ability to absorb frequent updates.
User Involvement	End users and other stakeholders can frequently engage throughout development.	End users and other stakeholders cannot support frequent interaction with the development team or the target end user cannot be accessed.
Project Scope	The software development is mostly limited to the application layer while using existing infrastructure and existing external systems.	The development spans core capabilities and underlying platform or infrastructure.
System Integration	The software developer is responsible for integration of their software with most/all other systems.	The development team does not want to own system integration responsibilities for their system.
System Criticality	The software can be operational at a basic level, with some defects that can be addressed in future releases, or the software can be iterated to a highly stable state within the desired timeframes.	The system cannot tolerate many defects, especially those that jeopardize other systems or have negative public consequences.
Developer Expertise	The software developer has relevant domain experience and Agile development expertise.	Agile development expertise is unavailable or the development team lacks domain experience.
Program Management Expertise	The software developer's program management team has Agile training, experience, or coaches.	The development team's program management team has no Agile experience or funding for Agile training or coaches.
Team Size	Software development can be effectively managed by a small cross-functional team and/or larger sets of software development teams can be managed inside a Scrum of	Multiple development teams are involved and must be coordinated.

Assessment Area	Consider Agile practices if	Consider V-Model practices if
	Scrums approach.	
Collaboration	Stakeholders and software developers can collaborate frequently and effectively.	Stakeholders are physically located across multiple locations and have limited bandwidth to support frequent collaboration.
Complexity	One or a few teams can perform software development.	Many teams are required to develop and integrate capabilities and functions into the total system.
Test Environment	The software development team can leverage test infrastructure and automated tests during software development. Testers are active throughout software development.	During development testing can only be performed on lower-level capabilities and functions. Significant system-level operational testing is required and can only be performed after development and integration of lower-level capabilities and functions.
Leadership Support	Leadership actively supports Agile software development practices and provides “top cover” to use non-traditional processes and methods. They are also directly involved in the mitigation of project blockers.	Leadership prefers a traditional development approach or is unfamiliar with Agile practices. Leadership doesn’t typically get involved with daily issue mitigation.

In summary, the program-level SE approach discussed earlier in Section 3.2 describes how SE techniques will be applied to decompose program SoS into lower-level elements. The decomposition process is complete when the system architecture is understood and documented well enough to drive procurement and development of lower-level capabilities and functions. When the decomposition process identifies a lower-level component that requires development, the Agile versus V-Model selection criteria detailed above will be applied to determine the development methodology to be used.

As discussed in Section 4.1.3, if the V-Model development methodology is selected for a specific project, there may be an opportunity to later transition the development from V-Model to Agile. For example, once the requirements have been defined through the V-Model, the selected vendor selected may use an Agile approach to quickly refine and extend the capability of their existing product, especially those parts of the design that have been implemented in software. As a result, the SE approach allows for three overall development approaches, namely Agile, V-Model, or V-Model with a transition to Agile.

Chapter 5. Program Documentation

5.1 Program Documentation Management Plan/Archive

The Smart Columbus program is comprised of numerous planning, engineering, outreach, and other related documents, all of which are necessary for successful execution of the program. Several of these documents are program-level, encompassing some or all the projects, whereas other documents are project-specific. Documents which support or are outputs of the SE process, including this SEMP, follow this same pattern, with both program level and project level documentation. Further, specific to the SE process, there are both USDOT deliverable items, as identified in Section 4.4 of the PMP, as well as internal engineering documents and artifacts that will be produced. These documents are subject to the process for document management and archiving, however, those identified as deliverable items may have additional levels of review and configuration control implemented.

Chapter 5 of the PMP serves to clearly document the process for document management, including collaboration, naming conventions, and access permissions. The SharePoint collaboration portal will be used for documentation collaboration between the USDOT, City of Columbus, and consultant staff at both the program and project levels. This portal will also act as the repository for all document artifacts. Multiple versions of several documents may be developed throughout the duration of the program. These versions will be maintained on the portal. All document contributors will be granted the necessary permissions to create and edit documentation in this environment, and as such, it is expected that all SE artifacts, both working and complete, shall be maintained on this portal.

The PMP details the standard naming convention for all deliverable items, but for quick reference, the following convention is used:

- <Smart Columbus tag>
- <USDOT NOFO Task Letter>
- <Project Abbreviation>
- <Document Name>
- <Document Status>
- <Version>

As an example, the final CVE ConOps will be named as follows; “SCC-B-CVE-CONOPS-FINAL-v1” where:

- SCC is <Smart Columbus tag>
- B is <USDOT NOFO Task Letter>
- CVE is <Project Name>
- CONOPS is <Document Name>
- FINAL is <Document Status>

- v1 is <version>

In addition to above document management tools, the City will use a web based repository for software development source code control and related artifacts. Chapter 5 of the PMP documents the organization and management of this both the SharePoint libraries and Agile code/documentation.

5.2 Program Documentation

Several documents and artifacts will be produced over the course of the program; many of which will depend on the specific SE process utilized to design an individual project. These project-specific documents are identified in Section 5.3 below. Program-level documents, which may address one or more projects, include this SEMP, the SoS ConOps, the System Architecture and Standards Plan, and the Demonstration Site Map and Installation Schedule. Each of these are discussed immediately below.

5.2.1 System of Systems ConOps

Building on the approach embodied by the SCOS, the City will produce a SoS ConOps that will describe the City's holistic, integrated approach to meet the deployment goals and how operational practice should be altered based on the introduction of these new technologies. Among other elements, the ConOps will include a system context diagram, which explicitly identifies all known external systems and interfaces to which the SCOS will interface, strategy for engaging external system owners to implement these interfaces, a discussion of enhancements to current operational practices, and use cases or scenarios, particularly those that show the interaction between the various projects and the SCOS.

5.2.2 System Architecture and Standards Plan

The City of Columbus is part of the Central Ohio Regional Intelligent Transportation System Architecture, based on the National ITS Architecture. A program-level System Architecture and Standards Plan will be developed comprising all projects. The architecture will be based on the CVRIA and developed using the Systems Engineering Tool for Intelligent Transportation (SET-IT). Once the program architecture is developed, individual project architectures will be added to the Architecture and Standards Plan to expand on the program architecture.

The Lead Systems Engineer, with assistance from the PMO SE/QS will oversee the development of the program architecture to ensure consistency between the CVRIA (SET-IT), the Central Ohio Regional Architecture (Turbo), and the National ITS Architecture. In the event updates are required to the Regional Architecture, the Lead Systems Engineer will notify the PgM to coordinate with Mid-Ohio Regional Planning Commission (MORPC) to update the architecture. The Lead Systems Engineer will also notify the PgM also if further coordination is needed with the CVRIA team to update the CVRIA and SET-IT based on Smart Columbus program architecture.

This is not a complete list of the standards that will be employed in the System Architecture and Standards plan. Various standards will be employed within and between the various projects, and will also be identified and documented as part of the standards plan. These standards are expected to include traditional ITS standards, emerging CV and automated vehicle (AV) standards, but also leverage numerous industry standards related to the SCOS, such as financial transactions, telecommunications, security, and transit planning.

5.2.3 Demonstration Site Map and Installation Schedule

The City will produce a draft Demonstration Site Map and Installation Schedule for delivery to USDOT. The Demonstration Site Map will identify the specific geographic area(s) and indicate locations related to key issues, current, and proposed roadside technology locations, CV and AV operations, and other explanatory features to support the City's proposed strategies.

The Site Installation Schedule will be produced as a subset of the Smart Columbus schedule, and will identify the specific infrastructure installation activities. For each type of infrastructure element to be installed, the schedule will indicate:

- Planned installation start and end dates
- Organization or individual responsible for the installation
- Milestone(s) identifying when the installation of each type of infrastructure element is completed
- Planned start and end dates for unit testing the operation of each infrastructure element (by type)

5.3 Project-level Documentation

The projects will deliver a set of documents based on the development methodology that is selected for each project. The PMP identifies the documents and artifacts to be produced for each project based on the selection criteria defined in Section 4.2 above. Note that even when a project will be delivered with the cooperation of a vendor or partner, the City PM and Project lead will maintain the oversight and production of all deliverables for delivery to USDOT. The vendor may be required to provide significant inputs to certain deliverables; this work would be specified in their RFP or agreement. Project-specific documents, organized by SE process, are as follows[13].

The required deliverables for Traditional V-Model Projects [deliverable number from PMP work breakdown structure] are identified in the bullets below.

- Concept of Operations [S2.X.1]
- Systems Requirements Specification [S2.X.2]
- Interface Control Document [S2.X.3]
- System Design Document [S2.X.4]
- Test Plan [S2.X.5 or S3.X.4]
- Testing Documentation [S2.X.6 or S3.X.5]
- O&M Plan [S2.X.6]

The System Design Document and O&M Plan in V-Model Projects incorporate installation requirements, and therefore, a stand-alone installation plan is not specified for these projects.

The following are the required deliverables for vendor-provided Existing Solution V-Model Projects:

- Technical Memo/Trade Study [S3.X.1]

[13] The value in the brackets [ ] following items in the list of deliverables and subtask headings refers to the WBS number as identified in Chapter 4 of the PMP.

- Interface Control Document (ICD) [S2.X.3]
- Installation Plan [S3.X.3]
- Test Plan [S2.X.5 or S3.X.4]
- Testing Documentation [S2.X.6 or S3.X.5]

5.3.1 V-Model Documentation

Documentation is a critical component of the V-Model process, describing each aspect of the system from ConOps to the completion of testing. The Smart Columbus Master Schedule will account for a complete review and approval of all required deliverables before moving on to the next phase of the process. However, the Smart Columbus PMO will ask USDOT to consider conditional approval to begin the next phase of a project when the draft is near-complete and requires only minor edits to finalize. This approval is at the discretion of USDOT; the Smart Columbus PMO will not move forward without explicit direction from the AO and AOR. This approach, if approved by USDOT, will allow the PMO to speed up development of later deliverables, and ultimately, final deployment.

5.3.1.1 V-Model Management and Collaboration Tools

A key aspect of documentation is the use of software tools that enable development, tracking, and traceability through the process. The tools the City intends to utilize for the V-Model process are listed in Table 12.

Table 12. V-Model Process Tools

Software Platform	General Use	Smart Columbus Applications
HELIX	Requirements Management	The City will use the HELIX tool to manage requirements by project to provide consistency between projects and update the SEMP. Please note that per IEEE guidance, Verification and Validation plans are part of the SyRS.
USDOT SET-IT	Architecture Development	The City will use SET-IT to develop architecture diagrams for the program as well as for individual projects, where applicable.
SharePoint	Document management and collaboration portal	The City has established a SharePoint for the program. This platform will be used for storing and sharing documents throughout the development process.
GitHub	Code management and repository	The City will establish a repository on GitHub for centralized storage and sharing of any code developed on the program.

5.3.1.2 V-Model Artifacts

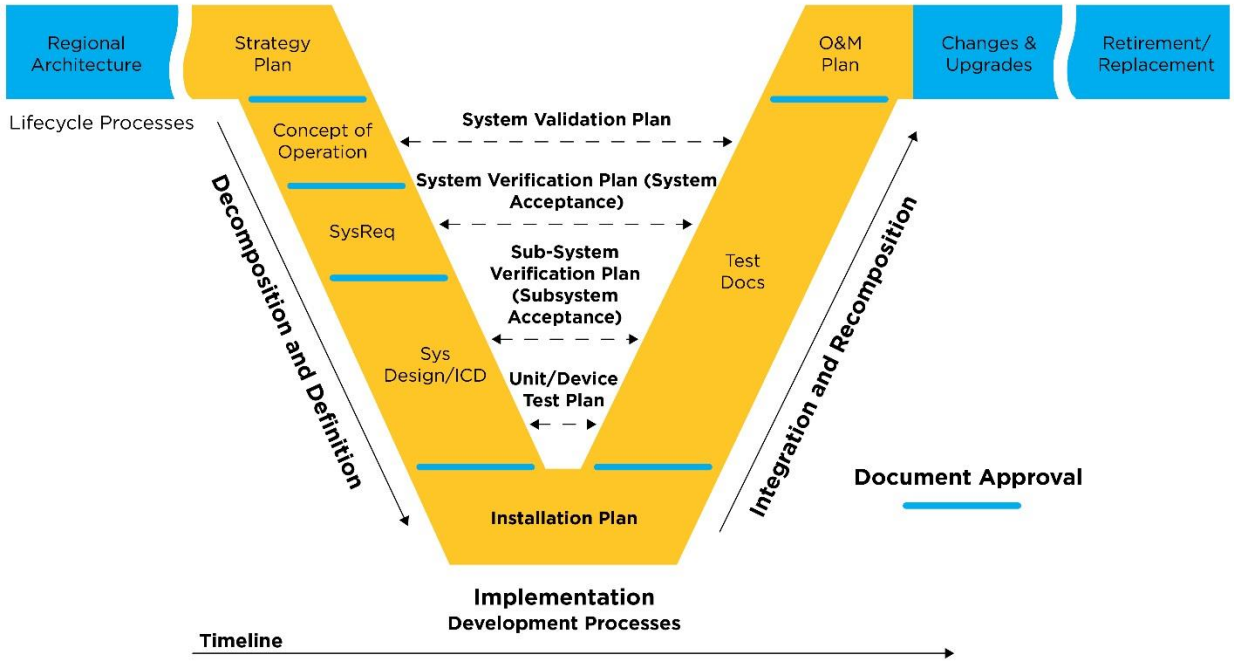
Artifacts developed for projects following the V-Model process are listed in Table 13, along with the standard/reference to be followed, whether it is a USDOT deliverable, and whether the City will conduct a walkthrough with the USDOT. Note: an entry of 'P' indicates that a walkthrough may potentially be

scheduled. For these artifacts, the Agreement does not require a walkthrough, but the City acknowledges that it may be beneficial conduct one if schedule and resources permit.

Table 13. V-Model Artifacts

Artifact	Standard/Reference	USDOT Deliverable	USDOT Walkthrough
Strategy Plan	Chapter 4.2.1 Project Strategy Plan		
ConOps	IEEE 1362-1998 (Concept of Operations) IEEE 1028-1997 (Software Reviews)	X	X
Systems Requirements	IEEE 1233-1998 (Systems Requirements) IEEE 1028-1997 (Software Reviews)	X	X
System Design	IEEE 1016-1998 (System Design Document)	X	P
ICD	TBD	X	
Installation Plan	TBD	X	
Test Documentation	IEEE 829-2008 (IEEE Standard for Software and System Test Documentation)	X	P
O&M Plan	TBD	X	

The Test Documentation will describe both system verification and validation and will be developed in conjunction with the ConOps (validation) and System Requirements (verification). Figure 10 depicts the relationship between the documents created for projects developed using the V-Model process up to the 508 Preparation. It should be noted that the test plans and documentation will include validation plans for tracing system elements/operations back to the ConOps, as well as verification (system acceptance criteria) plans for traceability to SyRS.



Source: City of Columbus, 2017

Figure 10. V-Model Methodology Documents

The projects use Technical Reviews to obtain feedback from appropriate stakeholders throughout the development process. These reviews are essential to ensure that each project meets its requirements and that the requirements are understood by the development team. The City will continue to conduct technical reviews of ConOps and System Requirements documents with the USDOT as were done with many of the ConOps already. The status of the project and additional needs gathering has been defined in Appendix D. These technical reviews are being conducted as walkthroughs based upon the guidance of Institute of Electrical and Electronics Engineers (IEEE) 1028-1997 and deviate where needed when the City determines it to be too restrictive for individual walkthroughs. In preparation of a walkthrough, the City provides the USDOT a "Walkthrough Package" consisting of the document to be reviewed and a comment resolution form for which to enter comments. The City then schedules, coordinates, and conducts the review. Technical and project personnel, along with a recorder and moderator are provided to facilitate the meeting. The stakeholders previously engaged and the broader city teams are invited to participate in the review. The City then submits a comment resolution report to the USDOT, containing the results of the review.

Other V-Model technical reviews will consist of sending documents out for stakeholder review and comment. If comments indicate user needs are not properly addressed or misunderstood, the City may choose to conduct a walkthrough of the document. The business owner will chair the meeting, while the Project Lead conducts the walkthrough. The Lead Systems Engineer will support the Project Lead, asking probing questions of the audience to elicit the nature of the original comments and concerns, including but not limited to:

- User needs or requirements changed
- Stakeholders identify new user needs or requirements
- Existing user needs or requirements are no longer relevant
- The team misunderstood the user needs or requirements

5.3.1.3 Existing Solutions in the V-Model

Existing solutions will either be operational or ready for deployment by a partner, therefore, documentation may differ. The City will deliver sufficient user needs documentation in the form of ConOps and requirements documentation in the form an ICD to allow an acquisition of a vendor product that will meet the needs of the City. The documentation will contain a high-level description of the system functionality, status and stage of development, and integration approach. ICDs describe interfaces that should be established between the existing system, the SCOS, and interfaces to other systems that might exist. The City PM and Project Lead will have oversight and responsibility for delivering these items to USDOT, but vendors/partners will likely provide some level of contribution. The following subset of V-Model documents will also be delivered:

- Installation Plan
- Test Documentation
- O&M Plan

Installation Plans and Test Documentation will be developed to ensure consistent deployment and to validate system functionality and traceability to the ICD. O&M Plans will also be developed, describing the functionality and operations of the systems, as deployed.

In the event updates are required to the Regional Architecture, the PgM will coordinate with MORPC to update the architecture. The PgM will also coordinate the CVRIA team to update the CVRIA based on Smart Columbus.

5.3.1.4 V-Model Templates

The following documents will serve as templates and guides for developing documents for the V-Model process:

- The National ITS Architecture
- CVRIA
- The Central Ohio Regional ITS Architecture
- INCOSE Systems Engineering Handbook, Fourth Edition
- FHWA Systems Engineering for Intelligent Transportation Systems
- IEEE 1362-1998 (Concept of Operations)
- IEEE 1233-1998 (Systems Requirements)
- IEEE 1016-1998 (System Design Document)
- IEEE 1028-1997 (Software Reviews)
- IEEE 830-1998 (IEEE Recommended Practice for Software Requirements Specifications)
- IEEE 829-2008 (IEEE Standard for Software and System Test Documentation)

All Templates can be found on the Task B: Systems Engineering Approach section of the SharePoint. User needs within a document will use the following numbering convention:

- <Project Abbreviation>
- <Subproject Abbreviation> (if applicable)
- UN<3-digit User Need number>

- v<2-digit version number>

As an example of a user need for the Transit Pedestrian Indicator application under the CVE, would be CVE-TPI-UN001-v01; where:

- CVE is <Project Abbreviation>
- TPI is <Subproject Abbreviation>
- UN001 is UN<3-digit User Need number>
- v01 is V<2-digit version number>

Requirements within a document will use the following numbering convention:

- <Project Abbreviation>
- <Subproject Abbreviation> (if applicable)
- <reqtype><3-digit Requirement Number> where <reqtype> is:
  - FN: Functional
  - PR: Performance
  - IF: Interface
  - BH: Behavior (e.g. states and modes, stimulus response, fault and failure handling)
  - OC: Operational Conditions (e.g. safety, dependability, human factors, environmental conditions)
  - TP: Transportation
  - ST: Storage
  - PC: Physical Constraints
  - RE: Realization
  - IN: Integration
  - VE: Verification
  - VA: Validation
  - PD: Production
  - MA: Maintenance
  - DC: Disposal Constraints
  - RG: Regulation[14]
  - v<2-digit version number>

As an example of a Functional Requirement for the Transit Pedestrian Indicator application under the CVE, would be CVE-TPI-FN001-v01; where:

- CVE is <Project Abbreviation>

[14] This Requirements Type List is from the INCOSE Systems Engineering Handbook revision 4

- TPI is <Subproject Abbreviation>
- FN001 is <reqtype><3-digit Requirement Number>
- v01 is v<2-digit version number>

5.3.2 Agile Documentation

As with other software development methodologies, documentation is important within the Agile methodology. However, Agile documentation is provided in a real-time, continuous, and transparent manor, evolving along with the product, rather than upfront as its own process.

The following are deliverables related to the Agile process:

- Strategy Plan [S4.X.1]
- Management and Collaboration Tools Administration [S4.X.3]
- Product Roadmap and Release Planning [S4.X.4]
- User Story Definition [S4.X.5]
- Development [S4.X.6]

5.3.2.1 Agile Management and Collaboration Tools

An important aspect of the transparent documentation is use of software tools to enable stakeholders to access centralized and up-to-date content during all development stages. The tools the City intends to utilize for Agile process are listed in Table 14. These tools and how to access them are described in depth in the PMP in Chapter 5.

Table 14. Agile Tools

Software Platform	General Use	Smart Columbus Applications
Pivotal Tracker	Agile Project Management software	The City will use Pivotal Tracker (https://www.pivotaltracker.com/n/projects/1946257) to manage all Scrum backlog and sprint progress by the development team.
SharePoint	Smart Columbus document management and collaboration portal	The City has already established a SharePoint for the program. This platform will be used for storing and sharing all development artifacts throughout the development process.
GitHub	Code management and repository	The City will establish both a private and public repository on GitHub for centralized storage and sharing of any code developed on the Program. The private repository will be used for content management of iterative development code and

Software Platform	General Use	Smart Columbus Applications
		documentation. Once items are deemed production-ready and shareable by the Business Owner, the relevant code and documentation will be moved into the public repository.
SlackBot	Customized user communications tool	The primary way bot users interact with people on a given workspace is by connecting to the Real Time Messaging Application Programming Interface (API) and opening a websocket connection with Slack. The Events API is an alternative way to receive and respond to events as a bot user contained within a Slack App.
Hubspot	Customer relationship management tool	The City has already established a Hubspot application to track the status of partnership development; Hubspot will also be used for new opportunity engagement, use case development and data owner identification and engagement in the Agile process for the SCOS.

5.3.2.1.1 Agile Artifacts

Scrum's artifacts represent work or value to provide transparency and opportunities for inspection and adaptation. Artifacts defined by Scrum are specifically designed to maximize transparency of key information throughout the development process. Artifacts developed for projects following the Agile process are listed in Table 15, along with the standard or reference to be followed, whether it is a USDOT deliverable, and whether the City will conduct a walkthrough with the USDOT. The artifacts will be refined and extracted from the Agile project management software at the end of every Sprint (typically every two weeks).

Table 15. Agile Artifacts

Artifact	Standard/Reference	USDOT Deliverable	USDOT Walkthrough
Strategy Plan	Chapter 4.2.1 Project Strategy Plan		
Product Backlog	Developed and Managed through Pivotal Tracker		Viewable in real time through Pivotal Tracker. Reviewed with USDOT at the

Artifact	Standard/Reference	USDOT Deliverable	USDOT Walkthrough
			end of each sprint
Product Increment	Developed and Managed through Pivotal Tracker	X	Viewable in real time through Pivotal Tracker. Reviewed with USDOT at the end of each sprint
Sprint Backlog	Developed and Managed through Pivotal Tracker	X	Viewable in real time through Pivotal Tracker. Reviewed with USDOT at the end of each sprint
Sprint Retrospectives	Developed and Managed through Pivotal Tracker. Documented and posted to SharePoint as soon as completed	X	Viewable in real time through Pivotal Tracker. Reviewed with USDOT at the end of each sprint

Hyperlinks to all artifacts will be provided in the City's quarterly progress report to the USDOT.

5.3.2.1.2 Existing Solutions in the Agile Model

Even though existing solutions will either be operational or ready for deployment by the partner, the City will utilize the Agile process to integrate the system into the overall program and with other projects as appropriate. For systems that require development to provide data or capability, a complete Agile process will be utilized. For existing solutions that do not require development, Sprints will be utilized to integrate the system into the program.

5.3.2.1.3 Agile Templates

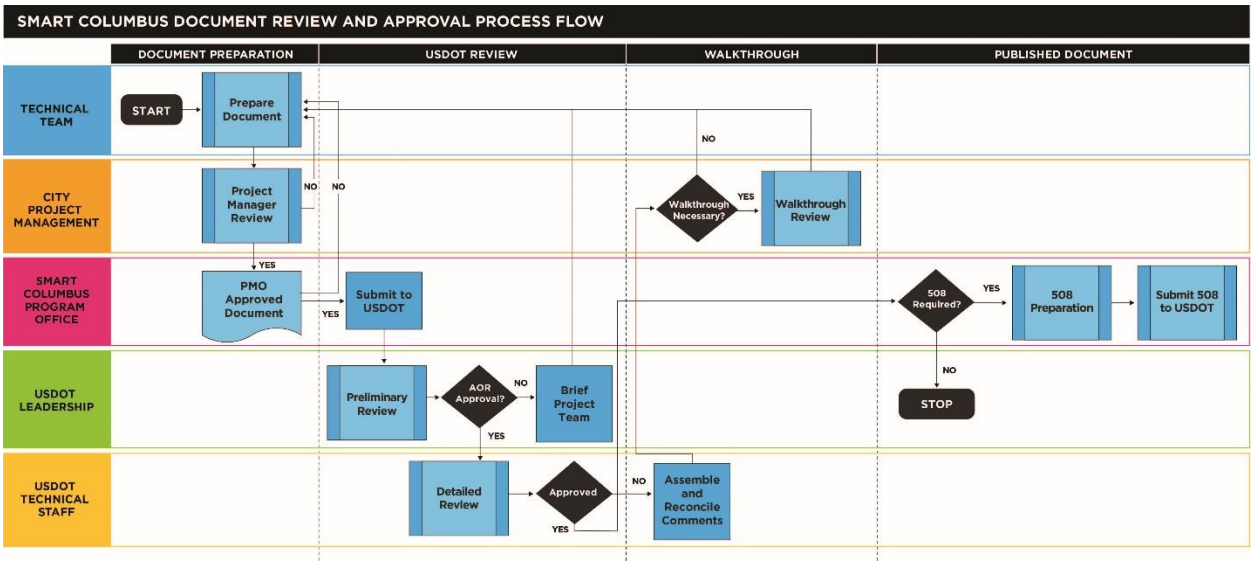
Since the program will have multiple projects using the Agile process, the City will establish the following standard template formats. These standard template/guides will be stored in the SharePoint:

- User Stories and Acceptance Criteria: https://www.scrumalliance.org/community/articles/2013/september/agile-user-stories for examples and best practice guidance.
- Retrospective: https://www.scrumalliance.org/community/articles/2016/october/a-template-for-easy-scrum-retrospective-preparatio for examples and best practice guidance.
- Definition of Done Checklist: https://www.scrumalliance.org/community/articles/2008/september/definition-of-done-a- reference for examples and best practice guidance.
- Scrum Master Checklist

All Templates can be found on the Task B: Systems Engineering Approach section of the SharePoint (https://smartcolumbusprogram.sharepoint.com/TaskBWorking/Forms/ContentType.aspx).

5.4 Documentation Review Process

Figure 11 identifies the steps delineated by the City, in cooperation with USDOT, to review and ultimately publish deliverable items associated with the Smart Columbus program. This process will be followed for all documentation that requires the approval of the City PgM as well as acceptance by the USDOT Agreement Officer Representative. As shown, reviews by the City PM, USDOT technical staff, and the project technical team are all indicated. Further, decisions on inclusion of a walkthrough or need to produce a 508-compliant document are also shown by responsible party. Figure 11 below indicates a general time progression of the project document review process but is not meant to indicate a specific period of time.



Source: City of Columbus, October 2017

Figure 11. Document Review and Approval Process Flow

5.5 Interface Control Process

5.5.1 Program Dependencies

The SCOS ties all projects together. All projects are expected to send data to the SCOS to be used by other projects as well as for performance measurements. Figure 6 depicts the relationship of the SCOS to the other Smart Columbus Projects, as well as the City, USDOT, and third-parties.

While most projects are expected to have a dependency on the SCOS for operational data, some projects may have dependencies on other projects and city systems.

For Smart Columbus, a dependency is defined as when one project requires data or functionality provided by another project to meet its objectives. In general terms, a data consumer will have a dependency on a data producer. For example, the MMTPA/CPA project, to provide the user the best travel options, will require data from the SCOS (producer). Therefore, the MMTPA/CPS project would have a dependency on the SCOS and supported transportation service providers. Data consumers and producers may also have dependencies on communication technology or infrastructure to retrieve or provide data. For example, the CVE will depend on a backhaul network to send data to the SCOS. Some dependencies, however, could be limited to one or more features and not the entire project. For example, Truck Platooning may have a dependency on the CVE, but only for the Freight Signal Priority functionality. The Platoon function may require Dedicated Short-Range Communications (DSRC) on-board units to be operational in the vehicles, but does not require DSRC Roadside Units (RSUs) to operate. DSRC RSUs connected to a properly configured signal controller are required, however, for the Freight Signal Priority functionality.

Table 16 depicts dependencies among the projects. The rows contain the nine projects that will have dependencies (i.e. the consumers). The columns contain the nine projects as well as other dependencies within the overall program (i.e. the producers). An “X” is placed in a cell if the project in the row (consumer) has a dependency on the project in the column (producer). For example, MMTPA/CPS is dependent on the SCOS, SMH, and transportation service providers (producers). In the matrix, rows represent a project that is impacted by another project or capability and the columns represent projects or capabilities that impact other projects. This enables effective scheduling and resource allocation. The City PM will update the Dependency Structure Matrix based on results from the stakeholder working groups meetings.

Table 16. Dependency Structure Matrix

Projects (Consumers)	SCOS	Connected Vehicle Environment	Multi-Modal Trip Planning / Common Payment System	Mobility Assistance for People with Cognitive Disabilities	Prenatal Trip Assistance	Event Parking Management	Smart Mobility Hubs	Connected Electric Automated Vehicles	Truck Platooning
SCOS		X	X	X	X	X	X	X	X
Connected Vehicle Environment	X							X	X
Multi-Modal Trip Planning / Common Payment System	X				X	X	X	X	
Mobility Assistance for People with Cognitive Disabilities	X								
Prenatal Trip Assistance	X		X				X		
Smart Mobility Hubs	X		X		X				
Event Parking Management	X		X						
Connected Electric Automated Vehicles	X	X	X						
Truck Platooning	X	X							

Appendix A: List of Acronyms

Acronym/Abbreviation	Definition
AI	Artificial Intelligence
AO	Agreement Officer
AOR	Agreement Officer's Representative
API	Application Programming Interface
AV	Automated Vehicle
BI	Business Intelligence
BRT	Bus Rapid Transit
CEAV	Connected Electric Automated Vehicles
CINO	Chief Innovation Officer
CMAX	Brand for COTA Cleveland Ave. Bus Rapid Transit
COTA	Central Ohio Transit Authority
ConOps	Concept of Operations
CPS	Common Payment System
CRM	Customer Relationship Management
CV	Connected Vehicle
CVE	Connected Vehicle Environment
CVRIA	Connected Vehicle Reference Implementation Architecture
DoD	Definition of done
DoR	Definition of ready
DoT	Department of Technology
DPgM	Deputy Program Manager
DSRC	Dedicated Short Range Communications
EAV	Electric Automated Vehicle
EHS	Enhanced Human Services
EPM	Event Parking Management
ETL	Extract, Transform and Load
FHWA	Federal Highway Administration
FMLM	First-Mile/Last-Mile
GIS	Geographic Information System
HDFS	Hadoop Distributed File System
I/O	Input/Output
ICD	Interface Control Document
IE	Independent Evaluator
IEC	International Electrotechnical. Commission
IEEE	Institute of Electrical and Electronics Engineers
IOT	Internet of Things
INCOSE	International Council on Systems Engineering

Acronym/Abbreviation	Definition
ISO	International Organization for Standardization
IT	Information Technology
IT PM	Information Technology Program Manager
ITS	Intelligent Transportation Systems
MMTPA	Multi-modal Trip Planning Application
MORPC	Mid-Ohio Regional Planning Commission
MVP	Minimal Viable Product
NEMT	Non-Emergency Medical Transportation
NOFO	Notice of Funding Opportunity
NoSQL	Non-Structured Query Language
O&M	Operations and Maintenance
PfMP	Performance Measurement Plan
PgM	Program Manager
PM	Project Manager
PMO	Program Management Office
PMP	Project Management Plan
PoC	Point of Contact
QA	Quality Assurance
Q&A	Question and Answer
QM	Quality Management
QMP	Quality Management Plan
RDBMS	Relational Database Management System
RFP	Request for Proposal
RSU	Roadside Unit
RVTM	Requirement Verification Traceability Matrix
SBS	System Breakdown Structure
SCC	Smart City Challenge
SCOS	Smart Columbus Operating System
SE	Systems Engineering
SE/QS	System Engineer/Quality Support
SEMP	Systems Engineering Management Plan
SEP	Systems Engineering Process
SET-IT	Systems Engineering Tool for Intelligent Transportation
SMH	Smart Mobility Hubs
SoS	System of Systems
SyRS	Systems Requirements Specification
TBD	To Be Determined
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
WBS	Work Breakdown Structure

Appendix B: Risk Register

The risk register serves as a way for the Smart Columbus Team to maintain a way to identify assumptions and evaluate and minimize risk. Technical Risk will be managed alongside all other program risks in accordance with Chapter 16 of the PMP.

Appendix C: Requirements Verification Traceability Matrix

Requirements Verification Traceability Matrix (RTVM)

Fields	Requirement No.	Chapter	Requirement Title	Operational Mode	Verification Method	User Need ID
Valid Values				Normal, Maintenance, Test, Degraded, etc	Test, Demonstrate, Inspect, Analyze	
Example	CVE-TPI-FN001-v01	TBD	Warning Indicator	Normal	Demonstrate	CVE-TPI-UN001-v01

Appendix D: Project Evaluation Matrix

Project Evaluation Matrix

Project	How Have Needs Been Identified? Comments?	Gaps (within Needs Analysis)	Deliverable	Stakeholders AND End-Users Identification	Score	Next steps
Connected Vehicle	Sources: • Linden outreach • Working groups (COTA, ODOT, City, County, USDOT, OSU). • Data analysis	1)Performance measure data source 2)Data processing needs 3)Appropriate reference to SCOS 4)Incorporate elements of removed projects (as needed)	ConOps	• Linden community session • Columbus Department of Safety, • COTA, Columbus Division of Fleet, • Connected Vehicles Working Group, • Franklin County, • Ohio Department of Transportation, • Ohio State University, Columbus • Department of Public Service Traffic Management, • Department of Technology, • Mid-Ohio Regional Planning Organization.	4	• Fill identified gaps • Modify ConOps and Submit

Project	How Have Needs Been Identified? Comments?	Gaps (within Needs Analysis)	Deliverable	Stakeholders AND End-Users Identification	Score	Next steps
Multi-Modal Trip Planning / Common Payment System	• Linden Outreach • Focus groups • Working groups • Individual outreach (transportation service providers, industry leaders, solution providers)	1)Combine CPS and MMTPA 2)Incorporate additional discovery 3) Address USDOT comments for CPS. 4)Show integration of CPS and MMTPA with SCOS	ConOps	• Linden community sessions; • Older adults focus group; • Young mothers focus group; • Dept. of Neighborhoods Linden Transportation Working Group; • Connected Travelers working group; • COTA; • MORPC; • Genfare; • Car2Go; • CoGo; • Transportation Service Providers; • Trip planning application developers; • Payment processing vendors; • SCOS development team	3	• Complete stakeholder engagement (COTA) • Synergize efforts. • Update ConOps

Project	How Have Needs Been Identified? Comments?	Gaps (within Needs Analysis)	Deliverable	Stakeholders AND End-Users Identification	Score	Next steps
Smart Mobility Hubs	• Still in discovery • Draft ConOps outline • Need to define stakeholders, process for engagement. This project has been on /off again leading up to reframe.	1)Coordination with Dept Neighborhoods w/g (this is a current city w/g that SC is a stakeholder in). Garner feedback / needs. 2)Engage with Linden community; garner feedback and needs from end-users in these discussions 3)Need to confirm location of hubs 4)Identify what needs exist for kiosks 5)Consider integration data needs 6)Coordinate with Recs & Park (user needs) 7)Coordinate with COTA / locations (user needs) 8)Coordinate with Columbus State (user needs)	ConOps	• Linden community sessions; • Dept. of Neighborhoods; • Transportation Working Group; • Connected Travelers working group; • OSU; • COTA; • Car2Go; • CoGo; • Transportation Service Providers; • Department of Recreation and Parks; • Columbus State Community College	1	• Identify and conduct engagement • Define and validate user needs • Draft ConOps

Project	How Have Needs Been Identified? Comments?	Gaps (within Needs Analysis)	Deliverable	Stakeholders AND End-Users Identification	Score	Next steps
Mobility Assistance	• Trade Study, with two rounds of USDOT comments addressed • Outreach conducted (end users, solution providers)	1)Update Trade study to include recommendation for solution and future state plans for solution; 2)Show integration with SCOS.	Trade Study	• Mobility Assistance Working Group; • Linden Community Sessions; • OSU; • COTA • Paratransit; • COTA Mobility Advisory Board; • AbleLink; • Mass Factory; • COTA Accessible Transportation Advisory Committee; • Franklin County BDD	5	• Update and finalize trade study
Prenatal Trip Assistance	• Still in discovery. • Sidewalk labs research complete • Identifying effort to determine additional stakeholders and end-users.	1)New project / all discovery needs to be done	Trade Study or ConOps (TBD)	No	1	• Learn more about state initiative • Finalize due diligence report.

Project	How Have Needs Been Identified? Comments?	Gaps (within Needs Analysis)	Deliverable	Stakeholders AND End-Users Identification	Score	Next steps
Event Parking Management	• Draft ConOps, with minimal comments returned from USDOT. • Some stakeholder engagement (Experience Columbus and garage owners, Short North Meetings) • W/G meetings established. • Attended Short North meetings.	1)Engage with additional end users (gravel lot owners, other actual end users of solution) 2)Integration expectations with MMTPA/CPS and SCOS 3)Review existing data sets 4)Identify needs for loading zones, charging stations and parking meters 5)Substantiate difference between proposed solution vs Parking Panda and other parking apps	ConOps	• City of Columbus Department of Public Service, Division of Traffic Management, • Division Parking Services, • Department of Technology, • End users (application users, Parking garage owners/operators, and surface lot owners/operators) • Experience Columbus.		• Meet with Inrix and Teva • Meet with users of app

Project	How Have Needs Been Identified? Comments?	Gaps (within Needs Analysis)	Deliverable	Stakeholders AND End-Users Identification	Score	Next steps
Connected Electric Autonomous Vehicle	• Draft ConOps complete and reviewed by USDOT • Lacks operational stand point - articulate operating conditions for the CEAV • Clear problem definition	1)Easton Survey 2)Make clear the scope of area included for CEAV 3)Need to reach out to LBrands / FMLM impact 4)Remove the signal prioritization from ConOps, handle in CV 5)Clarify integration with SCOS	ConOps	• Connected Electric Autonomous Vehicle Working Group; • Linden Outreach sessions; • Easton Area Developer (Georgetown) and Property Manager (Steiner & Assoc.); • Autonomous Vehicle Policy Working Group; • COTA; COTA riders; • Easton area workers (survey to be administered in November); • Vendors	2	• Incorporate feedback from Easton Surveys • Update ConOps from 1st draft based on comments and gaps
Truck Platooning	• W/g meetings • End user discussions (ODOT, Public Safety)	1)Review truck platooning vs. freight signal priority 2)Clearly capture SCOS integration 3)Confirm capabilities of other platooning systems for comparison	ConOps	• Truck Platooning Working Group; • ODOT; • ODPS; • City of Columbus Public Safety; • Logistics companies; • Peloton; • University of Arizona; • DENSO	4	• Determine FSP plan • Evaluate PATH solution vs Peloton • Submit ConOps with slight modifications based on gap

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