IoT for Smart City Services: Lifecycle Approach

Ahmed Hefnawy, Abdelaziz Bouras, Chantal Cherifi

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Ahmed Hefnawy
DISP Lab
Lyon 2 University
Lyon, France
ahmed.hefnawy@univ-lyon2.fr

Abdelaziz Bouras
DCSE, College of Engineering
Qatar University
Doha, Qatar
abdelaziz.bouras@qu.edu.qa

Chantal Cherifi
DISP Lab
Lyon 2 University
Lyon, France
chantal.bonnercherifi@univ-lyon2.fr

ABSTRACT
"Internet of Things" (IoT) and "Smart City" are widely recognized to address the complexity of modern city operation. Concentration of population, scarcity of resources and environmental concerns are the main challenges that face city operators, and make ordinary service provisioning less efficient. In city environment, IoT sensors can be sources of real-time data; and, IoT actuators can execute real-time actions in the physical domain. IoT systems range from domain-specific to cross-sectoral systems where valuable data/ information flow across interconnected complex systems. Yet, to integrate domain-specific IoT systems into the complete vision of Smart City, as a System of Systems (SoS), there is a need to address heterogeneity of data sources, diversity of application domains and the big number of stakeholders across different phases of lifecycle. This paper suggests Service Lifecycle Management (SLM) concepts and Lifecycle Modeling Language (LML) to analyze, plan, specify, design, build and maintain IoT-enabled Smart City Service Systems.

Keywords
IoT, Smart City, Lifecycle, LML, SoS.

1. INTRODUCTION
IoT and Smart City services and applications are very well known to address the same problems of high levels of urbanizations. Concentration of population, scarcity of resources, sustainability and efficiency of city operation are the main challenges of urbanizations. The complexity of city operation is rising and ordinary service delivery solutions are becoming less efficient while residents are continuously aiming for better quality of life. The International Telecommunication Union (ITU) defines Smart Sustainable City as [1] *"an innovative city that uses Information and Communication Technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services…"*. The British Standards Institution (BSI) was even more specific when described this innovative smart city as [2] *"an effective integration of physical, digital and human systems in the built environment to deliver a sustainable, prosperous and inclusive future for its citizens"*. The integration of physical and digital/ cyber systems, in co-engineered interacting networks, is widely known as "Cyber Physical Systems" (CPS); or similarly, as "Internet of Things" (IoT) [3] which is defined as *"The global network connecting any smart object"*. The global connectivity feature of IoT fuels smart city with real-time data streams about certain characteristics of the real world; and hence, smart city services empower city operators with real-time decision-making enabled by real-time data streams from heterogeneous objects [4].

IoT-enabled smart city systems include domain-specific systems, like smart transport, smart parking, smart energy, smart water, etc. Yet, smart city can be more valuable and powerful when relevant data can be exchanged between different systems across different domains. IoT-enabled smart city service systems are parts of a complete ecosystem. The smart city ecosystem includes humans, whether users, policy makers, regulators, vendors, etc. The ecosystem has also business models and processes; and subject to applicable laws, policies and regulations. Finally yet importantly, the smart city ecosystem is more about the entire quality of life and living standards rather than isolated experiences [4].

Therefore, there is a need for a global approach that manages collected data, processed information and accumulated knowledge according to a lifecycle point of view; and allows seamless flow between different domains, across all phases of lifecycle. This vision leads to integrating domain-specific IoT systems into the complete ecosystem of Smart City. To achieve this vision, the integration of IoT systems should be considered during design, operation and maintenance. i.e., across different phases of lifecycle.

This paper proposes lifecycle approach for modeling IoT-enabled smart city service systems to better integrate people, processes, and systems; and assure information consistency, traceability, and long-term archiving. Similar to other engineered systems, the lifecycle aspect of IoT-enabled smart city service systems is very important to analyze and address concerns across different lifecycle phases; and, ensure systematic involvement and seamless flow of information between different stakeholders of the smart city ecosystem. The remaining of this paper is structured as follows: Section 2 describes related work. Section 3 explains the proposed Lifecycle Approach. Section 4 demonstrates the application of the proposed approach on Smart Parking. Finally, Section 5 sheds light on the conclusion of this paper and the proposed future work.

2. Related Work

2.1 Smart City
According to J. Jin et al. [7] smartness of a city is driven and enabled technologically by the emergent IoT. IoT are the most important data sources for a smart city [8], as illustrated in Fig. 1. Information Sources include IoT sensors deployed in a city environment; city information sources e.g. Open Data portals, city Geographical Information System (GIS) data etc. [10]; and, user generated information through social media e.g. microblogs such as tweets that have been proven feasible for city related event extraction. Information Sinks include IoT Actuators, City Datastores and social media channels through which cities could potentially push information to their citizens.

The Smart City Framework, as proposed by the City Pulse Project [8], consists of number of Functional Groups (FGs). The Large-Scale Data Analysis FG addresses issues related to integration of a large scale of heterogeneous sources producing real-time streams and their semantic enrichment. The Reasoning and Decision Support FG tackles issues related to the ability of the SCF to adapt

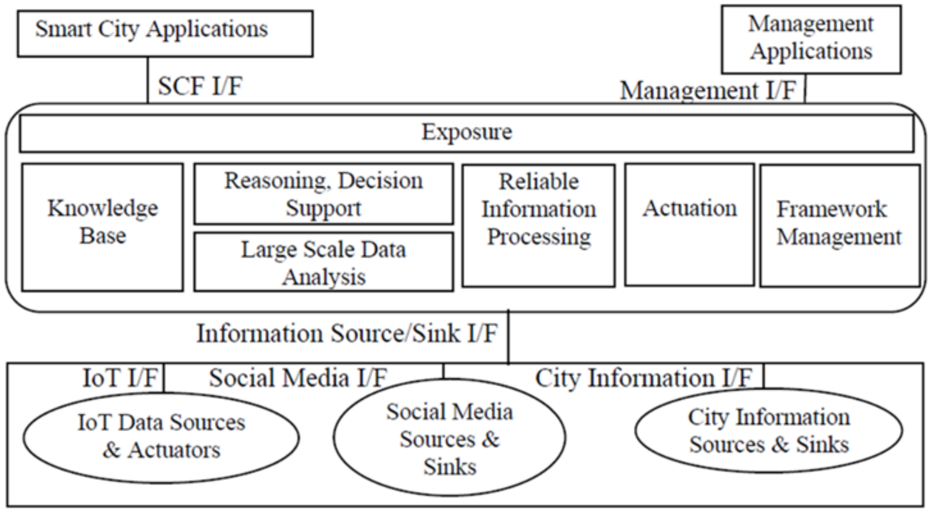

Fig. 1: Smart City Framework [8]

to alterations based on real-time information streams. It is mainly responsible for monitoring the semantically enriched streams and adapting the collection of stream information from one side and providing an API towards the Smart City Applications from another side. The Large Scale Analysis and Reasoning and Decision Support functionalities are supported by prior knowledge in the form of the Knowledge Base FG and Reliability and Quality of Information control mechanisms by the Reliable Information Processing FG.

2.2 Internet of Things (IoT)

The IoT Functional Model, as proposed by the IoT-A project [18], illustrated in Fig. 2, contains seven longitudinal Function Groups (FGs) (light blue) complemented by two transversal FGs (Management and Security, dark blue). The IoT Process Management FG relates to the conceptual integration of (business) process management systems with the IoT-A-ARM. The Service Organization FG is responsible for composing and orchestrating services of different levels of abstraction. It effectively links service requests from high level FGs such as the IoT Process Management FG, or even external applications, to basic services that expose resources and enables the association of entities with these services by utilizing the Virtual Entity FG. The Virtual Entity and IoT Service FGs include functions that relate to interactions on the Virtual Entity and IoT Service abstraction levels, respectively. The Virtual Entity FG contains functions for interacting with the IoT System on the basis of Virtual Entities, as well as functionalities for discovering and looking up services that can provide information about Virtual Entities, or which allow the interaction with Virtual Entities. Furthermore, it contains all the functionality needed for managing associations, as well as dynamically finding new associations and monitoring their validity. The IoT Service FG contains IoT Services as well as functionalities for discovery, look-up, and name resolution of IoT Services. The Communication FG provides a simple interface for instantiating and for managing high-level information flow. The Management FG combines all functions that are needed to govern an IoT system. The Security FG is responsible for ensuring the security and privacy of IoT-A-compliant systems.

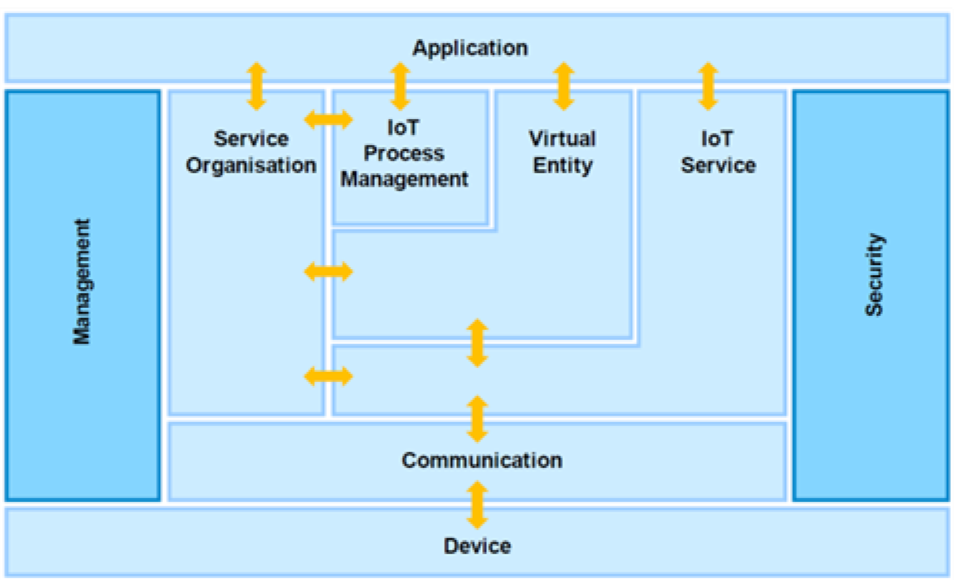

Fig. 2: IoT Functional Model [18]

2.3 Service Systems

J. Sum [12] describes service system as an ecosystem composing of people, process (service delivery process) and tools/ technologies. According to the author [12], the purpose of service systems is to deliver quality services to end customers. T. Böhmann et al. [13] call such quality service as "value co-creation". The authors [13] bring the notion of value-in-use and value-in-context to emphasize that value is often bound to a specific context. Services, particularly new emerging services, have distinguished characteristics like being: information driven, customer-centric, real-time in nature, e-oriented, and productivity-focused [12]. From another perspective, service system can be viewed as a system of systems (SoS), where individual, heterogeneous, functional systems are linked together to realize new features/ functionalities of a meta-system to improve robustness, lower cost, and increase reliability. The evolution toward SoS thinking is driven by the need to analyze, design, implement modern large complex systems which, in most cases, are composed of independently developed, operated and managed systems based on predefined stakeholders' requirements [14].

J. M. Tien and D. Berg define service system engineering as *"a multidiscipline that addresses a service system from a lifecycle, cybernetic and customer perspective"* [15]. Service Lifecycle consists of the following phases, illustrated in Fig. 3 [11]: definition and design (Beginning of Life, BOL), implementation and delivery (Middle of Life, MOL) and decommission (End of Life, EOL).

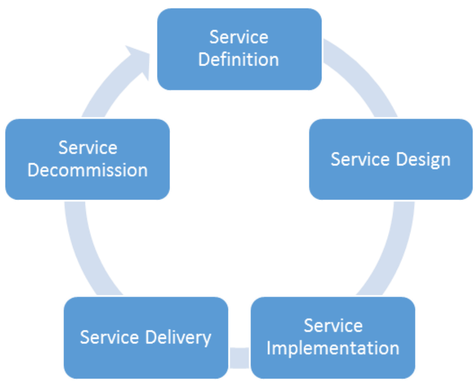

Fig. 3: Service Lifecycle Phases [11]

3. Lifecycle Approach

The role of IoT systems and smart city services is becoming bigger in daily city operation. Yet, most of those systems are vertically locked, where the data collection, processing, analysis and the resulting decisions and accumulated knowledge are normally locked within the boundaries of a particular domain: traffic, parking, energy, water, etc [6][9]. Although, it is not expected that complete convergence will happen between those verticals; seamless flow of information can help horizontal integration to be realized. Such integration is important for efficiency purposes, taking into consideration that some parts of the value chain are not fiscally feasible or administratively possible to replicate.

The proposed approach is based on decoupling information sources and sinks from real-time intelligence functions [5], as illustrated in Fig. 4. In the meantime, a new Lifecycle Management function can be introduced to manage data, versions, variants and the business processes associated with heterogeneous, uniquely identified connected objects. The Lifecycle Management shall support all phases of lifecycle; integrate people, processes, and technologies; and assure information consistency, traceability, and long-term archiving; while enabling intra/ inter-collaboration within the same city service system and with other systems.

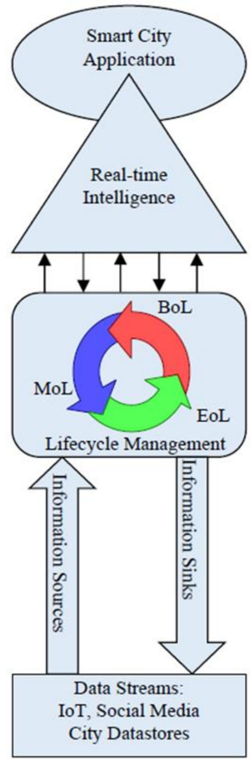

Fig. 4: Smart City: High-Level Conceptual Model [5]

Like other engineered systems, the lifecycle aspect of IoT-enabled smart city systems is very important to address concerns about the entire lifecycle of smart city components, including; product and service components, data, processes, applications, people and organizational structures [16]. The "IoT-enabled Smart City" has computational and physical components to provide smart city services. The type of applications in urban utilities and city services demonstrate "IoT-enabled Smart City" as a service system. Knowing the fact that "Smart City" can vary in scope and scale, there can be no one model fits all cases and applications. Moreover, for a certain city to be smart, this only happens through an evolution path that takes the city into a journey of deliberate steps. Hence, smart city service system is, in fact, system of systems (SoS) that do not necessarily designed and built simultaneously, or have the same lifecycle. Since innovation is one of the important features of smart city, smart city SoS should allow new Over The Top services and applications that can be geared with existing systems.

Smart city service systems can be deployed in many application domains. For ease of use, domains can be grouped and categorized when stakeholders have domain-specific and cross-domain concerns. A none exhaustive list of domains may include:

- Energy;
- Transportation;
- Environment;
- Disaster recovery;
- Agriculture;
- Health;
- Education;
- Infrastructure utilities;
- Etc.

The ITU Focus Group on Smart Sustainable Cities categorizes smart city stakeholders into the following groups [1]:

- Municipalities, City Council and city administration;
- National and regional governments;
- City services companies;
- Utility providers;
- ICT Companies (Telecom Operators, Start-ups, Software Companies);
- NGOs;
- International, Regional and Multilateral Organizations;
- Industry associations;
- Academia, research organizations and specialized bodies;
- Citizens and citizen organizations;
- Urban Planners;
- Standardization bodies

IoT-enabled smart city service systems may have all/ or some of the following features:

- Technology-intensive;
- Information-driven;
- Productivity-focused;
- Customer-centric;
- Innovative;
- Modular;
- Service-based applications;
- Value co-creation;
- Inter-disciplinary;
- Heterogeneity;
- Etc.

Like other engineering systems, IoT-enabled smart city service systems share similar Lifecycle Concerns, like [3]:

- Deployability;
- Disposability;
- Engineerability;
- Maintainability;
- Operatability;
- Procureability;
- Producibility;
- Etc.

Moreover, the SoS feature of smart city brings some more concerns. One of the concerns, the loose coupling of information sources from real-time intelligence functions (i.e. the collected data for certain smart service can be used by other smart city services); hence, sensors collecting particular data might be part of another service system other than the smart service of concern. In such a case, dependence between connected smart city service systems and traceability and trustworthiness of data across these systems should be addressed.

IoT-enabled smart city service systems can vary in properties and level of complexity, based on the applicable use case. Thus, the lifecycle aspect of IoT-enabled smart city service systems can be modeled using different Lifecycle Process Methods like: Waterfall, Reverse engineering, Agile, Lean, Service-based, Gap-Analysis, etc. General Service Lifecycle phases are still applicable on IoT-enabled smart city service systems, as shown in Fig. 3. Service Definition, Service Design, Service Implementation, Service Delivery, and Service Decommission. In the Service Design phase, requirements are analyzed and service system entities functions, interfaces, interoperability among service system entities, etc. are identified. Then, different service functions and requirements should be allocated to different service system entities by modelling concrete use cases under different scenarios. In the Service Implementation phase, information exchange and interactions among service system entities are ensured through service integration, verification & validation (IV&V) and proper testing methodologies. In the Service Delivery phase, service is continuously monitored to ensure meeting pre-set KPIs; and, continuous service improvement are utilized to analyze and set service improvements, potential service enhancements and to identify new service concepts across all entity types. The Service Decommission phase includes activities related to replacement or disposal of service or service system components [14].

4. Demonstration Case: Smart Parking

This Section demonstrates the proposed approach on one of smart city services, namely smart parking. With the increasing number of cars, parking becomes one of the challenges that face city operators, particularly in hot spots like, train stations, airports, shopping malls, stadia, etc. Smart parking can help in finding and allocating parking spaces, charging parking fees, and controlling illegal parking.

4.1 Description

This particular demonstration case is about using IoT-enabled smart parking system to provide parking service to visitors of a big shopping mall that has different types of stores, mega market for grocery and Cinema complex. The mall consists of 3 floors huge building, with 24 entrances evenly distributed. The building is surrounded by parking area against all the 24 entrances. In front of each entrance, 12 parking spaces are reserved for people with disabilities whose cars are registered accordingly. The administrators of the mall have faced some parking issues, particularly during busy hours. Sometimes, visitors do not know availability of empty parking spaces and cannot find them. Also, sometimes, visitors forget where did they park; and, waiting time at exits can be long.

4.2 Lifecycle Modeling Language (LML)

To visualize smart parking service system across different phases of lifecycle; hereafter, LML is used to apply Service Lifecycle Management (SLM) concepts. LML has the advantage of being a language that works across all phases and stages of the lifecycle: Requirements, Design, Acquisition, Verification, Operation & Support, and Disposal. LML is simpler than other System Engineering languages like SysML in terms of ontology and visual expressions. As per the LML specifications, “LML’s ontology provides a means to capture other program information, such as Artifacts, Statement/Requirements, Input/Outputs (e.g., deliverables), Risks, Decisions, Location, and Costs”. In addition, LML provides a set of relationships between Assets and Actions (Programs) that can capture traceability between different system components of SoS. In terms of time notion, the Time entity of LML can be used to capture specific milestones, which can then establish the relationship between the different system schedules; and visually, the Timeline charts show duration and start attributes, tasks and milestones as part of the program process model. LML defines the Action Diagram to enable better definition of logic as functional requirements. LML uses Physical Diagram to provide for abstraction, instances, and clones, thus simplifying physical models [19].

4.2.1 Beginning of Life (BoL), (Fig. 4)

Service Definition:

This is a smart parking service provided to visitors of the mall. This service aims to help visitors find parking space near to their desired entrance. The system also facilitate parking fee payment.

Stakeholders:

- Mall Administrators: who run the parking area belongs to the mall
- Visitors: who want to use parking service
- Billing Provider: who provide billing service to visitors (parking fees and parking vouchers)
- Police: law enforcement authority

Requirements:

- Place incremental fees and higher rate for peak hours
- API for smart phone app
- Accept parking vouchers and credit cards
- Interoperable with other smart city service systems

Functions, (Fig. 5):

- Read Plate Number
- Get User Profile
- Allocate Parking Spot (based on disability and nearest entrance)
- Update Registry
- Inform User (on his smart phone)
- Count Time
- Read Plate Number (at parking spot)
- (Do not)/ Give Access
- Detect Car dempark
- Update Registry
- Stop Timer
- Calculate Cost
- Inform User
- Charge User (using Payment Gateway)

Assets, (Fig. 6):

- Gate
- Plate Number Reader (at the gate)
- Parking Spot Sensor
- Parking Registry
- User Profile Datastore
- Payment Gateway

4.2.2 Middle of Life (MoL), (Fig. 7)

Service System Deployment:

Information exchange and interactions among service system entities are ensured through service integration, verification & validation (IV&V) and proper testing methodologies [14].

Service Delivery:

Service is continuously monitored to ensure meeting pre-set KPIs; and, continuous service improvement are utilized to analyze and set service improvements, potential service enhancements and to identify new service concepts across all entity types [14].

4.2.3 End of Life (EoL)

Service System Decommission:

Service Decommission phase includes activities related to replacement or disposal of the service or service system components [14].

5. Conclusions

Lifecycle aspect of IoT-enabled smart city service systems is of great importance to address lifecycle concerns. As a SoS, lifecycle concerns of IoT-enabled smart city service systems include exchange of information between different phases of lifecycle as well as traceability of information across different lifecycles. Heterogeneity of data sources, diversity of application domains and the big number of stakeholders are also concerns that can be addressed by the lifecycle approach. In general, the life cycle approach for IoT-enabled Smart city service systems intends to better integrate people, processes, and systems; and assure information consistency, traceability, and long-term archiving.

This paper presents Lifecycle Approach for IoT-enabled smart city service systems; however, further work is expected to apply the proposed approach on concrete use cases to build lifecycle based models of domain-specific applications. To ensure integration between all connected systems, The Open Group messaging specifications [17] may be used, which consist of two standards: the Open Messaging Interface (O-MI) that defines what types of interactions between objects are possible and the Open Data Format (O-DF) that defines the structure of the information included in the messages.

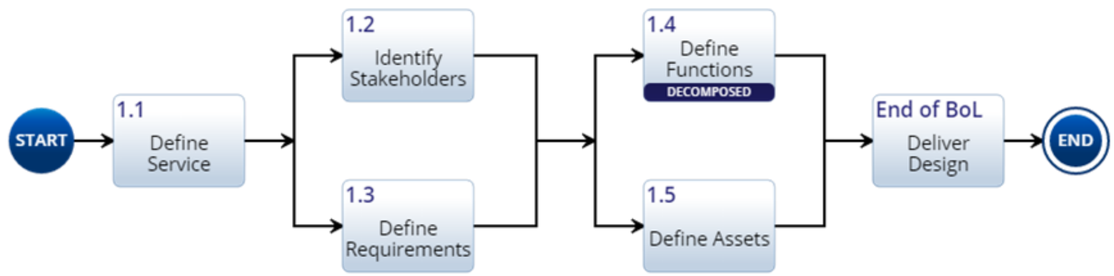

Fig. 4: Beginning of Life

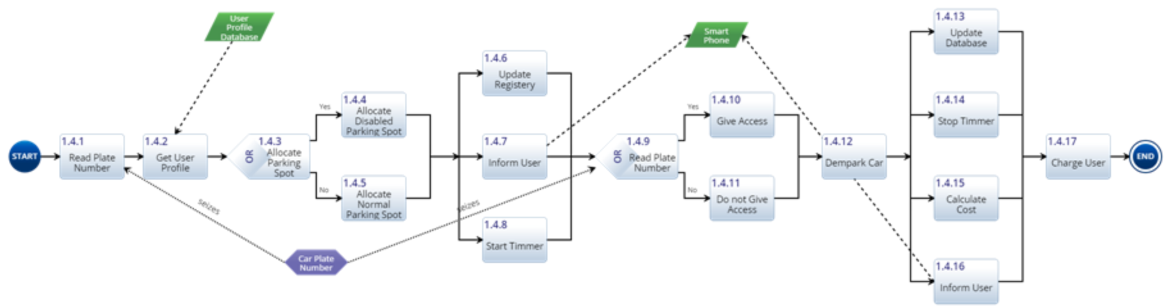

Fig. 5: Functions

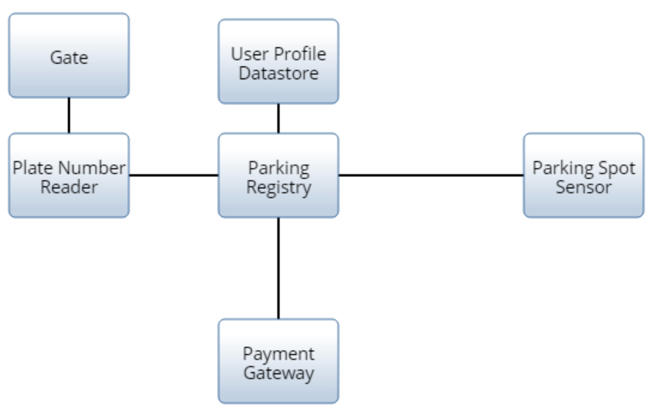

Fig. 6: Assets

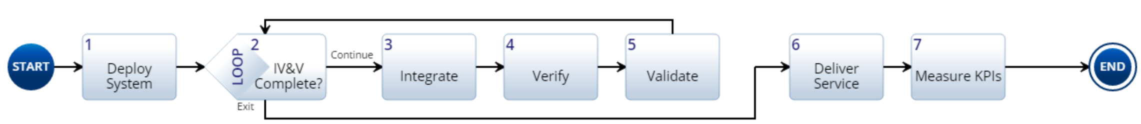

Fig. 7: Middle of Life

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