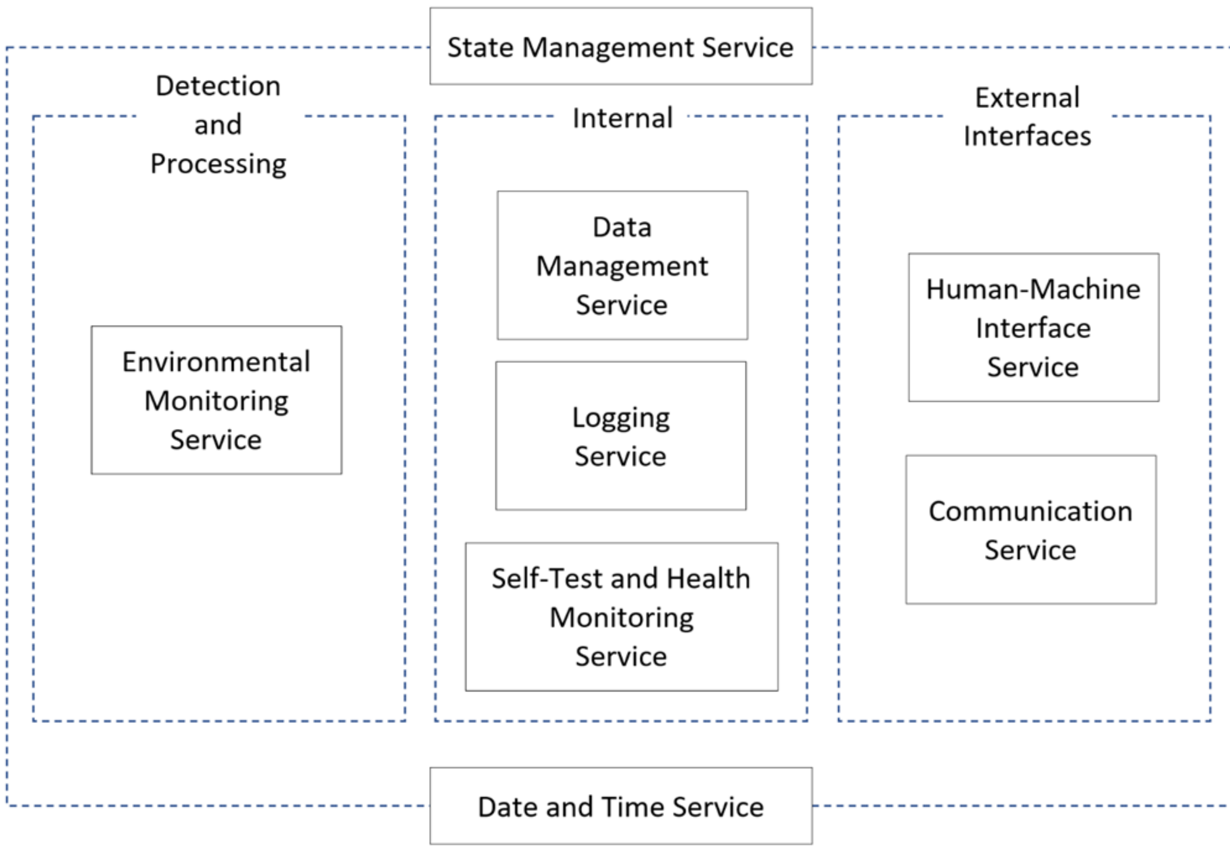
Automated Train Operations Sensor Platform Framework Requirements



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14. ABSTRACT
The Sensor Platform (SP) Framework was a system engineering project conducted in conjunction with the Association of American Railroads-funded development of automated train operation (ATO) system requirements. The SP is a device that monitors the external environment in front of the train for potential hazards and interfaces with other locomotive onboard (OB) systems to obtain operational data, archive data, and report hazards detected. The SP Framework project supported the ongoing FRA- and AAR-funded ATO development effort by developing an interoperable SP reference model and beginning the decomposition of the existing SP requirements into the services defined by the SP reference model. The SP Framework project produced a completed draft SP reference model and started progress on revised SP-reference-model based requirements documentation.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

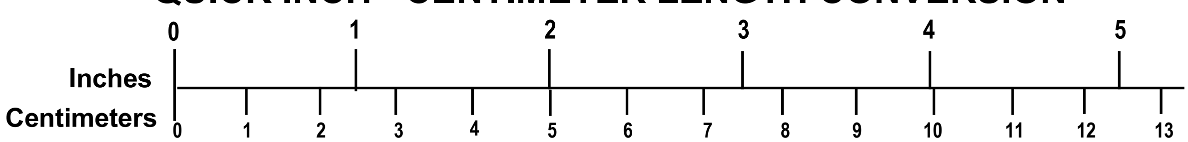
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

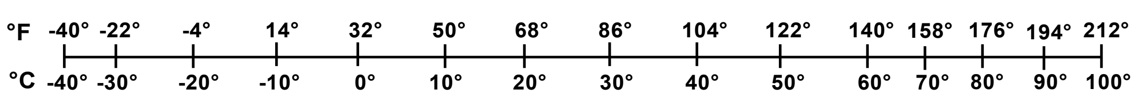
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Illustrations

Executive Summary

From September 2021 to September 2022, the Federal Railroad Administration (FRA) contracted Transportation Technology Center, Inc. (TTCI) to develop an interoperable Sensor Platform (SP) reference model to support automated train operations (ATO) and break down the existing SP requirements into the services defined by the SP reference model. This work was made possible through a project conducted in conjunction with the Association of American Railroads (AAR)-funded development of ATO system requirements. The authors used SP documentation developed during prior efforts and worked with the established ATO technical working group. The project deliverables were completed in three steps:

1. Developing SP conceptual documentation to support reference model development using the existing SP documentation
2. Developing a draft reference model to implement the SP concept as a set of services and allocating the services to SP subsystems
3. Decomposing and revising the existing SP requirements into the services defined by the reference model

The completed draft SP reference model, including the SP conceptual documentation, is included in Appendix A. Due to scheduling limitations, the completion of the draft SP requirements was not within the scope of this effort. An in-progress draft will be delivered to FRA at the end of the project performance period. The draft documents produced as part of this effort will be delivered to the AAR to be considered 1) for further development, 2) for use in ATO and other SP-related development efforts, and 3) for possible inclusion in the AAR *Manual of Standards and Recommended Practices* (MSRP). TTCI recommends continued work to complete the in-progress SP requirements documentation.

1. Introduction

An industry effort is currently underway to define the interoperable requirements for an Automated Train Operation (ATO) concept. ATO will be capable of supporting high automation, fully ATO under normal operating conditions on the line of road. The ATO concept includes a Sensor Platform (SP) to monitor the external environment ahead of the train. Previous efforts funded by the Federal Railroad Administration (FRA) and Association of American Railroads (AAR) produced a requirements document for an SP intended fulfill the needs of the ATO System of Systems (SoS).

To further promote the interoperability and consistency of operation and safety benefits, the industry determined further definition of the SP to be necessary. Further definition includes developing an industry-standard SP reference model followed by decomposing and refining the SP requirements into the services defined by the SP reference architecture. An industry-standard reference model is an abstract framework that describes a system as a complete set of conceptual components and is used in the design and standardization of a system (see Section 2.1).

1.1 Background

Automation is a means of improving the efficiency of North American freight rail operations while maintaining safety. To promote the development of interoperable train automation technology, an AAR effort to define requirements for ATO began in 2018 with the development of a Concept of Operations (CONOPS) for an interoperable ATO SoS. The ATO SoS leverages existing systems, including Interoperable Train Control (ITC) Positive Train Control (PTC) and ITC Energy Management System (EMS), with new technology to support train automation.

The seamless interchange of automated trains between multiple railroads requires interoperable ATO systems. To be interoperable, an ATO-equipped locomotive must be able to operate on any railroad's territory with the necessary infrastructure and must be able to be supported by any railroad's qualified personnel while allowing the flexibility for each railroad to design, procure, implement, and package ATO-related capabilities and interfaces according to its own business needs.

The SP under development is envisioned as a system that can serve as both an external environmental monitoring system for automated trains and a standalone system to fulfill other railroad needs.

1.2 Objectives

The objectives of the ATO Sensor Platform (ATO SP) Framework project included:

- Producing a draft interoperable SP reference model derived from the SP functional definition
- Starting to expand, refine, and decompose the existing SP requirements into lower-level requirements based on the new reference model

1.3 Overall Approach

The SP reference model is a decomposition of the SP requirements defined during the previous SP development effort (Stoehr, N., Dvorak, M., Gage, S., & Sheehan, R., 2023), and the model defines a set of discrete functions that may be allocated to SP architectural elements. Figure 1 provides an overview of the project inputs and tasks performed in this effort.

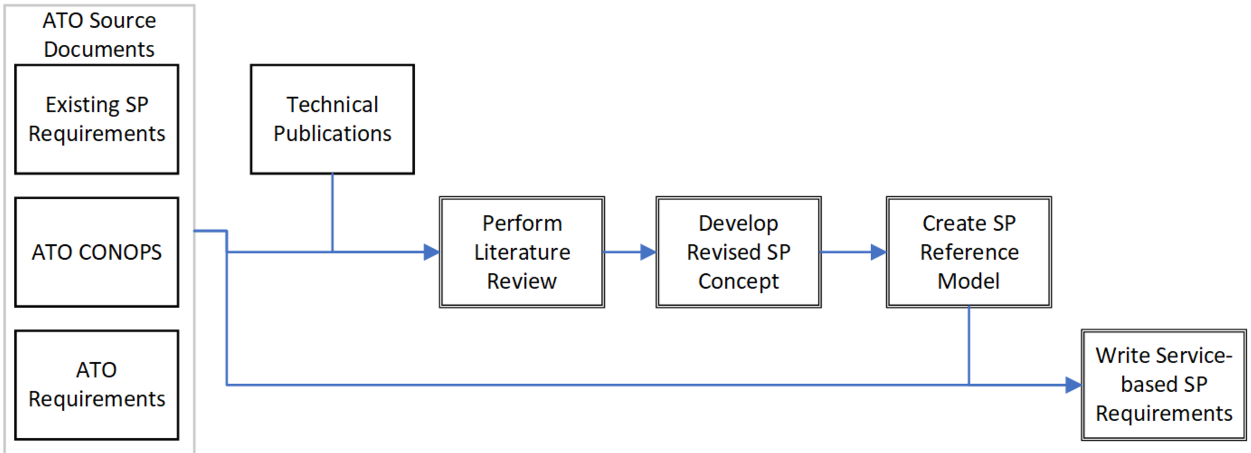

Figure 1. Project Flow Diagram

The inputs to this project included:

- The previously-defined SP requirements
- The ATO CONOPS
- The ATO requirements documentation
- Technical publications
    - This includes publications related to sensing and automated vehicles such as research papers, technical articles, and conference proceedings.

The tasks were then detailed as follows:

1. Perform a literature review. Reviewing technical publications aided in locating relevant public information that may inform the effort.
2. Develop the revised SP concept. This development involved the production of conceptual documentation to inform the reference model.
3. Create the SP reference model. This model is a collection of services that, when taken as a whole, define a complete SP. Each of these services provides a unique function necessary for the operation of the SP. The function of each service is defined, but the reference model does not include requirements for implementing the service.
4. Start writing service-based SP requirements. This process involves the decomposition, refinement, and expansion of the existing SP requirements into a new SP requirements document based on the reference model.
5. Documents produced under this effort may be developed further in a follow-on phase funded by FRA or through other industry efforts, with the possibility of including future versions of these documents in the AAR *Manual of Standards and Recommended Practices* (MSRP), at the discretion of the AAR.

1.4 Scope

The ATO SP Framework project included the development of a completed draft SP reference model and conceptual documentation necessary for supporting the reference model. The documentation was based on prior FRA and AAR-funded SP development work and limited to what was needed to support the reference model.

The requirements developed as part of this effort are part of a multi-phase project and work on these requirements will continue in forthcoming phases. The scope of the requirements development portion of the project was limited to what could be completed within the project schedule. As-is incomplete draft requirements will be delivered to FRA, and substantial additional work will be necessary to finish them.

1.5 Organization of the Report

This report is organized as follows:

- Section 1 provides an introduction and overview.
- Section 2 discusses the SP reference model development.
- Section 3 discusses the ongoing SP requirements development.
- Section 4 provides a conclusion.
- Appendix A contains the completed SP reference model draft.

2. SP Reference Model Development

An SP reference model was created to inform further development of the SP. This reference model defines a set of services that any minimum interoperable SP must provide. Each service is defined as performing a specific function within the SP, and the complete set of defined services forms a complete SP. Interactions and links between the services were also defined as needed, and the initial allocation of services to SP subsystems was outlined.

The SP reference model is intended to support the further decomposition of the SP into lower-level SP architectural elements. Railroads and vendors may choose 1) to build a single SP that implements all the described services, or 2) to have different vendors implement the two SP subsystems.

2.1 Reference Models and Services

A reference model, as defined in this document, is an abstract framework describing a system as a complete set of conceptual components. More specifically, a reference model:

- As an abstract framework, defines the concepts necessary for implementing a system but does not define or favor any specific implementation method.
- Describes a system using a small number of conceptual components, their relationships to each other, and their relationships to the outside world.
- Is limited to a specific environment and problem space.
- Does not favor a specific technological solution, class of technology, or vendor.

Reference model purposes included:

- Encouraging the standardization of system design.
- Fully describing the necessary components of a system.
- Supporting system standardization.
- Supporting the definition of interoperable requirements.

The units a reference model uses to describe a system vary depending on the type of system being described and the goals of the reference model. For example, a business reference model may describe a system that uses departments while a reference model for a computer system may use functional blocks. Central to the SP reference model are services that are a cohesive group of functions that accomplish a specific task. For example, a time-keeping service may be built with a set of functions that include the synchronization of time with the outside world, the maintenance of clock stability, and the distribution of time synchronization to internal components.

2.2 SP Concept Definition

Up-to-date SP conceptual documentation was produced to support the development of an SP reference model that provides the required functionality and provides readers of the reference model with an understanding of the SP. The existing SP documentation was reviewed and combined with the current train automation definition to produce an updated SP concept with an appropriate set of use cases. This effort resulted in conceptual documentation providing the required level of detail. The SP concept is defined in Section 2 of the SP Reference Model (see Appendix A), and it includes:

- Documentation of current operations that the SP may supplement
- SP modes of operation
- SP capabilities
- SP users and stakeholders
- SP operational description
- SP use cases
- SP-phased development information

The SP concept definition was based on pre-existing information and limited to the definition of the SP to support the development of a reference model.

2.3 Support for Phased Development

During this project, the advisory group requested that the SP be defined in a way that supports phased development. Phased development allows for the development and testing of a limited-use SP that is not suitable for high automation but still enhances railroad operation while providing an opportunity for safety improvements. A limited-use SP may then be evaluated and improved to meet additional requirements, leading to an SP that meets the needs of high automation.

The SP provides a set of functions, the sum of which provide for high automation but may be deployed using a phased approach that provides incremental benefit while proving SP functionality. These functions included:

- Clear path detection.
- Object of Interest (OOI) and Condition of Interest (COI) detection:
    - Detection and classification of OOIs in the foul and in the right of way (ROW) may be implemented in separate phases.
    - A railroad may prioritize detection and classification of certain OOIs and COIs, resulting in an incremental deployment based on the OOIs and COIs detected.
- Crossing guard verification.

A phased development may also include initial systems that assist a train crew and/or require human oversight while later systems support high automation. The benefits of phased development include:

- Expediting development of the SP by allowing early SPs to meet some but not all the requirements necessary for high automation
- Supporting the development of an SP that operates in a limited set of railroad environments and allowing the benefits of an SP in some areas without requiring that it meet the demands of every possible railroad environment

- Providing operational and performance data for use in developing more advanced SPs
- Providing training data for use in developing more advanced SPs

Because the SP may support levels of automation below high automation, the name was changed from ATO SP to SP. The SP reference model supports phased development by defining the set of services necessary for any SP while allowing those services to be implemented according to a limited set of SP requirements. An SP implementation built according to the reference model, but not meeting all the functional and performance requirements, may be revised and updated to meet more requirements later. With sufficient revisions, an SP implementation will then meet the requirements of high automation. However, if an SP implementation lacks any of the defined services, it will not be able to meet the requirements of high automation without adding the missing services.

2.4 Reference Model Definition Approach

Reference models are built in different ways that depend on the system to be modeled and the goal of the model. Several approaches to building a reference model were:

- Definition of several distinct interoperable subsystems
- Definition of multiple layers
- Definition of necessary services

Each approach is further defined in the following sections, and as discussed below, the definition of necessary services was found to be the best approach to the SP reference model. Researchers considered evaluating each of the listed approaches, and the nature and goals of the SP, as defined in the SP concept. Considerations impacting the SP reference model included:

- The SP gathers data from multiple sensors.
  - In remaining technologically neutral, the number and type of sensors are not specified at the reference model level.
- The SP processes the sensor data needed to detect environmental conditions.
  - One set of sensors may be used to detect all conditions, or different sensors may be used to detect different conditions
  - Multiple algorithms may be used to verify and cross-check the results
  - Different vendors and different railroads may use different numbers and types of algorithms
- The SP interacts with multiple well-defined locomotive onboard (OB) subsystems.
- The SP must be contained on the locomotive.
- The SP does not have direct communication with the outside world, and only communicates with the interface locomotive OB subsystems.
- The SP must meet applicable safety and regulatory requirements.

2.4.1 Definition of Interoperable Subsystems

The definition of several interoperable subsystems was considered an approach to defining an interoperable SP. In this approach, each SP subsystem would be defined in detail sufficient for implementation by different vendors. A complete set of SP subsystems would then be assembled into an SP. Meeting the railroad objectives with an interoperable subsystem approach would, at a minimum, result in the separation of the analysis engine(s) and sensor device(s). Possible approaches would involve detailed specifications for several sensor device(s), analysis engine(s), and other components.

The research team identified multiple difficulties with this approach:

- Unnecessary constraints placed on the implementation. The goal of a reference model is to create a conceptual definition of how a system is built without unduly constraining specific implementations. An interoperable subsystem-based approach works well when the nature of the problem requires a set of interoperable subsystems; this is not the case with the SP.
- Restrictions on data preprocessing. The level of preprocessing that should be done within the sensor devices is not clear. For example, some camera-based approaches distribute the workload and speed computation by having cameras segment the image and transmit only portions of an image. Other approaches make the full image from each camera available to the analysis system. SP vendors should be able to determine the degree of preprocessing necessary to support the algorithms they develop.
- Restrictions on the use of new classes of sensor devices:
    - Machine vision is a rapidly evolving field with innovative new algorithms and sensors being developed at a rapid pace. Selecting a standard set of sensors today will prevent developers from taking advantage of new sensor innovations that will take place over the next few years because the new sensors may not follow standards written today. A sensor class considered impractical today may be not only practical but essential in 5 years.
    - SP vendors should have the flexibility to take advantage of regulatory changes, e.g., the power and frequencies of radar are strictly regulated. If the regulations are changed to support greater use of radar in civilian applications (such as self-driving vehicles), SP vendors should be allowed to take maximum advantage of the changes.
- Restrictions on the use of new sensor device interfaces:
    - Detailed definition of the sensor device interfaces would require selection and standardization of the interfaces used. As with sensors, data communication interfaces are rapidly developing. Selection of an interface standard today is likely to prohibit use of superior sensor device interfaces that are not yet commercially available.
    - There is substantial competition between data streaming protocols, e.g., some vendors are closely following the GigE Vision and GenICam industry standards while Teledyne Dalsa is promoting their proprietary TurboDrive extension to those standards as a superior solution. In this rapidly developing industry, changes to these standards, new proprietary standards, and entirely new standards can be expected.

Selecting a specific set of streaming protocols is likely to result in the inhibition of the use of future innovations in this area.

- Effort required. Full definition of separate interoperable SP subsystems would require a substantially larger system engineering effort that would substantially increase development time, risk, and cost. At this time, no gain that offsets these downsides has been identified.

While overcoming these difficulties may be possible, a reference model based on the definition of interoperable subsystems was not considered the best approach for this project. Later efforts may use the reference model developed here to define interoperable subsystems.

2.4.2 Definition of Multiple Layers

Computational systems are frequently defined as a set of multiple layers. The lower layers provide basic services to support the upper layers. Each lower layer abstracts the services it provides, allowing developers of upper layers to complete their work without understanding or caring exactly how the lower layers provide low-level services. The Open Systems Interconnect (OSI) is a common example of a layered reference model and a good example for explaining how a layered reference model works. Used to define computer networking systems, the OSI model has seven layers:

1) Physical
2) Data Link
3) Network
4) Transport
5) Session
6) Presentation
7) Application

Different network device and software implementations provide one or more layers and use standardized interfaces to interoperate with other devices at different layers.

The power of this approach is demonstrated by the internet. A network administrator can select from a wide range of standardized components to build the network with dramatically different physical hardware all of which support the same data link protocols. A network administrator can select whatever internet service technology is best in the current situation without caring what networking technology is used by the connected computers.

While layered reference models are powerful for some applications, the layered approach is not a good fit for the SP due to the following problems:

- Layered reference models have a strong focus on defining the low-level implementation details of a system. The desired SP requirements focus heavily on the high-level implementation details necessary for the definition of the minimum interoperable requirements.

- An SP is expected to be composed of several analysis engines running on high-powered computer hardware combined with an array of sensors. This combination is not well-described by a layered reference model.
- A layered reference model does not map well to the functionality that has been defined in the existing SP requirements document.

While a layered reference model could be made to work, it was not the best approach for this project.

2.4.3 Definition of SP Services

Another approach to defining an interoperable SP reference model is to identify and define all the services an interoperable SP requires. Each service is a logical function or set of closely related functions, and the full set of services forms a complete SP. Each service can be defined to the extent necessary to support interoperability. Interfaces are also defined only to the extent necessary to support the interoperability of the SP as a whole. An SP defined using this approach could be procured from a single vendor or the services may be allocated to distinct subsystems and several vendors could be hired to work together to provide the subsystems them with an SP.

Using this approach, each identified service is defined to the level of detail necessary based on the nature of the service. Some services may be defined in detail to promote the commonality of the SP operation while other services may be defined with minimal detail to leave room for railroads and vendors to innovate.

This approach also supports the decomposition and redefinition of the existing SP subsystem requirements. Each requirement can be reviewed, allocated to specific service(s), and decomposed as needed.

An additional advantage is that most of the problems defined as interoperable subsystems (see Section 2.4.1) are avoided. Requirements can be written to define the behavior and the requirements of each service. However, the specifics of the sensors necessary to implement the requirements, as well as the specific protocols and interfaces connecting them, are left to the vendors. As a result, each vendor can select the computational hardware and sensors best suited for the analysis engine(s) at the time the SP is designed, taking full advantage of new technological developments.

After considering the other approaches listed above, the definition of SP services was selected as the best solution to the problem. The SP does not fit a layer-based approach, and the definition of SP services provides a more flexible reference model than the other approaches to defining an SP reference model.

2.5 Development of a Service-Based Reference Model

Once the research team selected the “definition of SP services,” the services necessary for an interoperable SP were identified and defined. The definition of a service includes:

- A narrative description of the core functionality the service performed.
- Details on the objectives/functions performed by the service.
- A list of the key interfaces to other services.

The definition of each service must support requirement development and allocation of services to subsystems (if desired), and, unlike a CONOPS, the definition of services outlines the architecture of a device, not just what it does.

2.5.1 Services Defined

A list of the identified and defined SP services is below. A complete description of each service can be found in Section 3 of the SP Reference Model (Appendix A).

- State Management Service. The SP will have multiple states, and this service handles transitions between SP states.
- Date and Time Service. This service synchronizes both the SP's clock with the locomotive OB and the time across internal SP components to support data acquisition, fusion, and analysis.
- Self-Test and Health Monitoring Service. This service verifies the operation of the SP during initialization and monitors the SP health during operation.
- Environmental Monitoring Service. This service performs the core functionality of the SP, i.e., monitoring the environment around the train and reporting detected information.
- Communication Service. This service handles all communication between the interfaced locomotive OB subsystems and the SP.
- Logging Service. This service handles the logging of events and status information, archiving of sensor data, and sending data to the Locomotive Data Acquisition and Recording System (LDARS).
- Data Management Service. This service maintains up-to-date copies of all operational data (e.g., PTC track database) and provides them to other services as needed.
- Human-Machine Interface. This service provides a minimal interface for roadway workers to interact directly with the SP.

2.6 Allocation of Services to Subsystems

The railroads also requested that, as part of this effort, the research team considered the SP specification as multiple subsystems. To support this request, a service-to-subsystem allocation was performed (see Section 4 of the SP Reference Model in Appendix A). This allocation is intended to support the specification of multiple subsystems while avoiding the challenges listed in Section 2.4.1.

3. SP Requirements Development

The goal of the reference model-based requirements development effort is to decompose and refine the existing SP requirements into a new set of requirement documents based on the reference model. The completion of this requirements document was not within the scope of this project, and it is expected to be continued as part of another project.

3.1 Approach

The requirements development approach can be outlined as follows:

- Develop an outline for the new reference model-based requirements.
- Review the existing SP requirements document
  - Identify requirements that can be copied and revised
  - Identify requirements that require decomposition
  - Identify the service(s) to which a given requirement should be assigned
- Review other ATO-related requirements documents that may inform SP requirement development.
  - Identify requirements similar to those being written for the SP; these requirements may inform and speed SP requirement writing
  - Identify requirements that may impact SP behavior
  - Identify characteristics of the other ATO requirements documents that the SP requirements should have
- Write new SP requirements as part of the reference model-based requirements document.

Because this effort is underway, there are several outstanding issues under consideration:

- The number of new SP requirements documents that will be needed.
  - The number of documents is an organizational decision and is not expected to change the level of work required.
- The exact relation of the new SP requirements document and old SP requirements document to other ATO and non-ATO requirements documents.
- The degree to which the new SP requirements will need to support development of separate SP subsystems by separate vendors.

4. Conclusions and Recommendations

In this project, TTCI worked with the advisory group to:

- Develop SP conceptual documentation
- Develop an SP reference model
- Start development of revised SP requirements

The conceptual documentation and reference model will inform future SP requirements development, inform a phased ATO development approach, and lead to the development of an SP that supports uses other than ATO.

The next steps recommended by the research team are:

- Complete the development of the revised SP requirements
- Revise and update the reference model and requirements as ATO and other SP uses are refined by the ongoing ATO development program

5. References

Stoehr, N., Dvorak, M., Gage, S., & Sheehan, R. (2023). *Automated Train Operations (ATO) Safety and Sensor Development.* Technical Report No., Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

Abbreviations and Acronyms

ACRONYMS	EXPLANATION
AOI	Area of Interest
AAR	Association of American Railroads
ATO	Automated Train Operations
ATO Ex	ATO Executive Subsystem
ATO SP	ATO Sensor Platform
ATOSS	ATO Support Systems
ATO SoS	ATO System of Systems
BO	Back Office
BODS	Back Office Decision Support
BOS	Back Office Server
CROR	Canadian Rail Operating Rules
CONOPS	Concept Of Operations
COI	Condition of Interest
EMS	Energy Management System
FRA	Federal Railroad Administration
GCOR	General Code of Operating Rules
GPS	Global Positioning System
HOT	Head of Train
HMI	Hunan-Machine Interface
ICD	Interface Control Document
ITC	Interoperable Train Control
ITC-ATOSS	Interoperable Train Control ATO Support System
ITC-EMS	ITC Energy Management System
ITC-PTC	Interoperable Train Control Positive Train Control
LDARS	Locomotive Data Acquisition and Recording System
MSRP	Manual of Standards and Recommended Practices
OOI	Object of Interest
OB	Onboard
OSI	Open Systems Interconnect

ACRONYMS	EXPLANATION
PTC	Positive Train Control
RCL	Remote Control Locomotive
ROW	Right of Way
SPCD	Sensor Platform Condition Dataset
SP	Sensor Platform
SoS	System of Systems
MSRP	Manual of Standards and Recommend Practices
TBC	To Be Configured
TBD	To Be Determined
TTCI	Transportation Technology Center Inc.
TCCO	Train Control, Communications, and Operations

Appendix A.
Sensor Platform Reference Model Draft

Prepared by Transportation Technology Center, Inc.

August 11th, 2022

1. Introduction

With the ongoing increases in computer performance and improvements in sensor technology multiple industries are now pursuing advanced environmental detection systems for a wide range of applications. Computer-based systems now integrate data from multiple cameras, radar, lidar, and other sensors and analyze the combined data stream to produce actionable information. One area of substantial development has been sensor systems for autonomous vehicles. Current systems allow automotive on-board computers to detect potential hazards and automatically initiate responses.

The rail industry is developing specifications for a Sensor Platform (SP) to monitor the environment in front of a train. As envisioned the SP would report the distance to which the route ahead is clear, detect potential hazards, and monitor the state of some railroad equipment. The SP will not initiate any train responses. The SP reports what it detects to other onboard systems, and those systems may initiate a train response. An SP system may be used as a stand-alone system or as part of an Automated Train Operation (ATO) system.

1.1 Document Purpose and Scope

This document defines an interoperable reference model and the overall operating concept for a locomotive onboard SP. The reference model defines the necessary services which must be performed by an interoperable SP. This document does not provide any SP system requirements. SP system objectives, operating concept, operating environment, and uses are also documented to support the SP reference model. This document describes an SP reference model, and it is not intended to be an exhaustive concept of operations for the SP system.

1.2 SP Purpose and Scope

The purpose of the SP is to provide an automated path clear and hazard detection system for use as part of the ATO System of Systems (ATO SoS). The SP is not intended to be a collision avoidance system and will serve only as a detection system. The SP's primary responsibilities are detecting the distance to which the in front of the train is clear, detecting Objects of Interest (OOIs), and detecting Conditions of Interest (COIs) within the foul volume and wayside. OOIs and COIs are classified using predetermined categories and, along with the clear distance, are provided to the ATO Executive (ATO Ex) subsystem as actionable information. The SP is expected to perform these tasks at least as well as human train crews.

1.3 Reference Models

As used in this document, a reference model is an abstract framework describing a system as complete set of conceptual components.

A reference model:

- Is abstract; it defines the concepts necessary for implementing a system but does not define or favor any specific implementation.
- Describes a system using a small number of conceptual components, their relationships to each other and their relationships to the outside world.
- Is limited to a specific environment and problem space.

- Is technology agnostic; it does not favor a specific technological solution, class of technology, or vendor.

The purposes of a reference model include:

- Encouraging standardization of system design.
- Fully describing the necessary components of a system.
- Supporting system standardization.
- Supporting the definition of interoperable requirements.

1.4 Document Outline Overview

This document is broken into four major sections:

- Section 1: Introduction. The introduction provides an overview of the document, definitions of terms, and a list of reference documents.
- Section 2: SP Concept. The SP concept section provides adequate SP conceptual documentation to provide context for the reference model and a background for verifying that the reference model performs the intended function.
- Section 3: SP Reference Model. This section illustrates the reference model and documents the services from which the reference model is built.
- Section 4: Subsystem Allocation. This section allocates the services to possible SP hardware subsystems.

1.5 Nomenclature

The following definitions apply within this document.

Table A2. Terminology

Term	Definition
ATO SoS	The term ATO System of Systems (SoS) is used to define the collection of systems (i.e., interoperable train control-Positive Train Control [ITC-PTC], ITC-EMS, and interoperable train control-ATO support system [ITC-ATOSS]) that interact and perform the functions necessary to support interoperable ATO train operations.
Clear distance	The distance along the track centerline of the train's route for which the foul volume has been verified to be clear of obstructions.
Condition of interest (COI)	1. An environmental condition that presents a potential derailment or damage hazard to the train. 2. An abnormal track condition which presents a potential derailment or damage hazard to the train 3. A railroad appliance the state of which must be observed upon approach by the lead locomotive of a train.
Intercept distance	The closest distance along the train route at which an OOI's trajectory prediction interval intersects the foul volume at the predicted location of the train.
Object of interest (OOI)	1. An object in the foul volume ahead of a train that presents a collision hazard to a train. 2. An object in the ROW that may move into the foul volume and present a collision hazard to a train. 3. A person or vehicle in the ROW. 4. An object in the foul volume of an adjacent track that presents a collision hazard to a train operating on the adjacent track.
Obstruction	An OOI within the foul volume.

Term	Definition
Prediction interval	A standard statistical term used to refer to an interval in which a future observation is, to a given degree of certainty, predicted to fall.
Sense distance	The maximum distance along the track centerline of the train's route in which the sensor platform is capable of detecting all obstructions within the foul volume. Detection of an object within the sense distance does not necessarily include classification. The sense distance depends on environmental conditions, sensor platform capabilities, and sensor platform health.

2. SP Concept

During conventional operations the train crew is responsible for monitoring the environment in front of the locomotive. The SP is a device that will automatically perform this function. The SP is not a complete replacement for the train crew.

The SP is intended to automatically detect if the intended route ahead of the train is or is not free of obstructions and hazards, and to detect other environmental conditions of interest (e.g., state of wayside appliances, presence of roadway workers on adjacent tracks). The SP provides information to external applications onboard a locomotive regarding the state of the path ahead of the train and the nature of and distance to detected obstructions and hazards. The scope of the SP is limited to monitoring of the foul volume and ROW in front of the leading edge of the lead locomotive. This includes detection collisions with potential hazards in the foul volume but does not include detecting objects colliding with the side or end of the train. The scope of SP environmental monitoring is driven by the environmental monitoring expectations of the train crew as defined by railroad operating rules, railroad operating practices, and when applicable regulatory requirements. Duties of the train crew include many activities that are out of scope for the SP, including responding to environmental conditions. Train automation functions are also out of scope for the SP, although the information provided by the SP may be used to assist train automation systems.

Information provided by the SP may be used to support train automation functions, road remote locomotive control operation, and enhanced train crew situation awareness applications. While specific use of SP-provided information is at the discretion of the deploying railroad and is not addressed, the SP concept description provides context to expectations of SP function and performance based on railroad expectations of train crews and needs of potential applications consuming SP information.

2.1 Role of the Train Crew in Environmental Monitoring

The train crew currently monitors the foul volume, ROW, the track, and the roadbed. Examples of objects and conditions the crew monitors for include:

- Foul volume
    - A clear path in front of the train
    - Obstructions
        - NORAC General Rule F, Movement of Trains 80A
        - Implied by GCOR 6.21
        - CROR, 802 Speed & definition of Track Unit Speed
    - People inside the foul volume
    - Vehicles inside the foul volume
    - Rolling stock
        - GCOR 6.27
        - NORAC 121 C

    - Applied derails
        - GCOR 6.27
- ROW
    - Roadway workers on an adjacent track
    - Oncoming trains
    - Fires
        - GCOR 1.28
        - NORAC 118
        - CROR 14 (3)
    - Signals
        - GCOR 1.47.C.2
        - NORAC 94 A
    - Fuses
        - GCOR 5.6
        - NORAC Miscellaneous Signals 14
        - CROR 11
    - Permanent Speed Signs
    - Crossing protection activation status
        - GCOR 6.32.2
        - NORAC Rule 138 C
        - CROR 103.1 (h)
- Track & Roadbed
    - Track damage (e.g., sun kinks)
    - Washouts, unsupported ties

In severe cases (major fires, washouts, etc.), GCOR 2.10 Emergency Calls requires the crew to make an emergency callout for conditions that threaten trains other than their own.

2.2 SP System Objectives

The SP monitors the area in front of the train and provides actionable information to interfaced locomotive OB subsystem(s). The SP must report the distance to which the path has been verified as clear, as well as identify objects and conditions in front of the train with at least the same fidelity as existing train crews.

2.2.1 The SP and the Locomotive OB

The SP interacts with other locomotive OB subsystems to:

- Obtain necessary operational data
- Log data
- Provide an up-to-date list of detected environmental information.

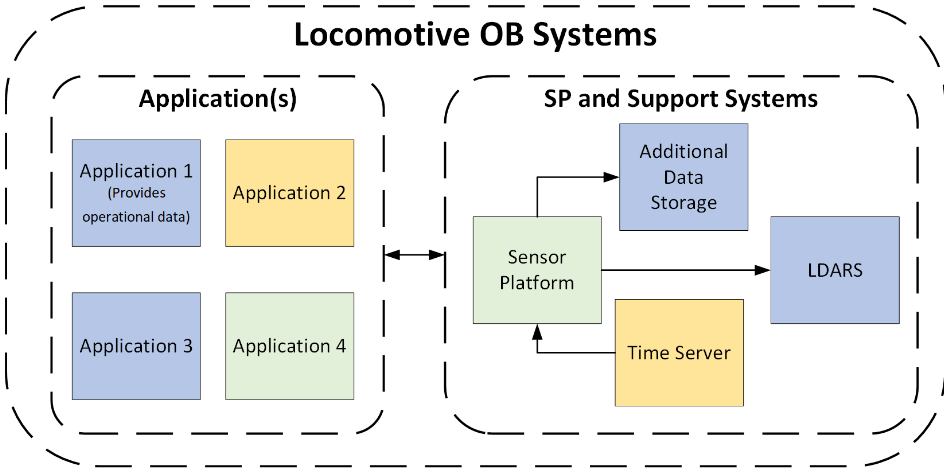

Figure A1. SP Interaction with OB Systems

2.2.1.1 SP Interaction with Application(s)

As shown in Figure A1, the SP interaction with other interfaced locomotive OB subsystem(s) is core to SP functionality. The interfaced locomotive OB applications must provide the SP with operational data, including the PTC track database, current position, and the train route. The SP then provides the interfaced locomotive OB applications with a continuously updated report on the environment ahead of the train; this includes a clear path report, a list of OOIs, and a list of COIs. The interfaced subsystem(s) can then use this information to inform train operations.

2.2.1.2 SP Interaction with Additional Data Storage

The SP may archive data to external data storage as needed. This may include raw or processed sensor data, as well as SP operational data, for use in evaluating and developing the SP. The additional data storage may be used to record data for training future versions of the SP software.

2.2.1.3 SP Interaction with LDARS

The Locomotive Data Acquisition and Recording System (LDARS) provides crash-hardened memory for preserving logs in the event of catastrophic damage. The SP supports logging critical data to LDARS, as required by regulations, and railroad requirements.

2.2.1.4 SP Interaction with ITC Time Server

The SP synchronizes with the ITC-compatible locomotive OB time server as specified in S-9363 Interoperable Train Control (ITC) Time and Location – Interface Control Document (ICD). This prevents timestamp-related errors in the messaging between the SP and the other locomotive OB subsystems. It also allows the SP to timestamp OOI and COI reports using the same time base as the locomotive OB. The SP also assumes that any external messages of which include timestamps are using the same time base as provided by the ITC time server.

2.2.2 Environmental Monitoring

While in the active mode the SP monitors the environment ahead of the train for objects of interest (OOIs) and conditions of interest (COIs). OOIs are objects which must be observed by the SP and reported. COIs are environmental and wayside equipment conditions which must be observed by the SP and reported. The OOIs and COIs detected by the SP are the same OOIs and COIs monitored by the crew in conventional operations (See Sections 2.2.2.2 and 2.2.2.4)

2.2.2.1 Areas of Interest

As shown in Figure A2, the areas of interest (AOI) (the region monitored) by the SP are divided into the collision volume, the foul volume, and the wayside. The exact length and width of the area to be monitored will be decided as part of the requirement development and ATO safety program. Notionally, the length may be up to about 2,000ft and the width may include about 30ft on either side of the foul volume.

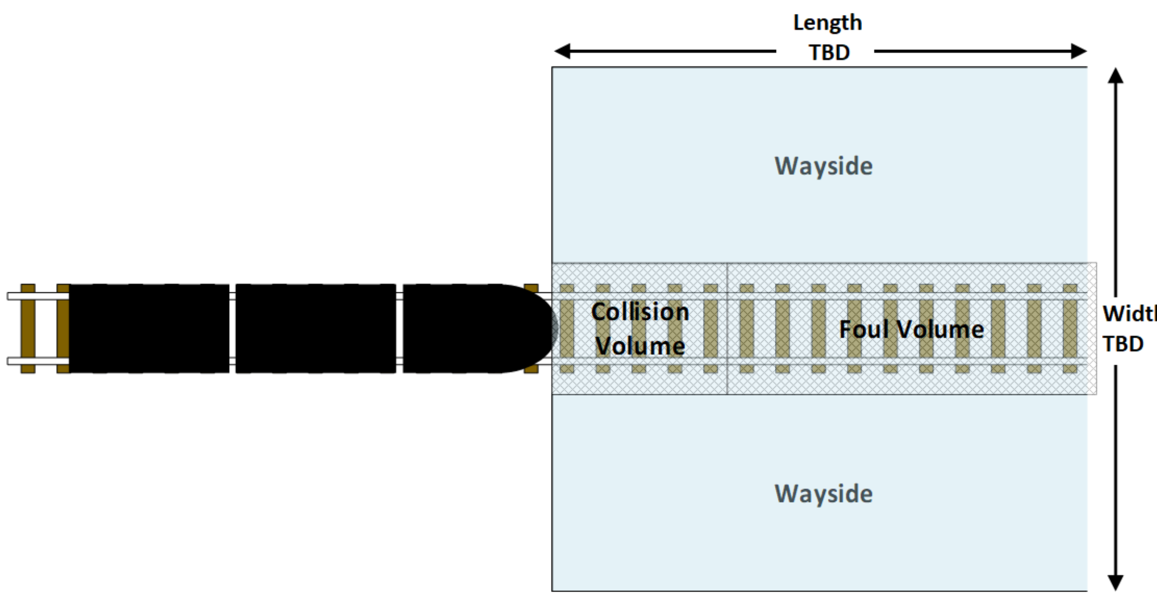

Figure A2. Monitoring Zones (not to scale)

When an OOI is detected in the foul volume or the wayside the SP reports the region in which the object was detected along with other information. If an OOI is detected within the collision volume (including OOIs that move into the collision volume) the OOI is considered to have collided with the train. This is reported a collision.

2.2.2.1.1 Collision Volume

The collision volume is the segment of the foul volume extending immediately in front of the leading edge of the locomotive. The collision volume is sized such that objects or conditions detected within the collision volume while the train is in motion are unavoidable and with which the locomotive is about to collide. When an OOI is detected in the collision volume the SP reports the collision to ATO Ex as a collision.

2.2.2.1.2 Foul Volume

The foul volume is the volume through which the train will pass. For the purposes of detecting OOIs and COIs, it extends, for a TBD length, along the intended route in front of the leading edge of the locomotive. The exact horizontal and vertical profile of the foul volume is specified by the AAR clearance plate to which the track was built. When the intended route is shorter than the TBD length, the foul volume ends at the end of the intended route.

2.2.2.1.3 Wayside

The wayside is the two areas adjacent to either side of the foul volume. For the purposes of detecting OOIs and COIs, the wayside also extends the same length as the Foul Volume along the train route in front of the leading edge of the locomotive. The wayside extends outward TBD feet from the track centerline. Vertically it reaches from the ground to the top of the foul volume; the SP is not required to monitor for objects above the foul volume of the AAR clearance plate to which the track was built.

2.2.2.2 Clear Path Detection

The SP reports the distance to which the intended route has, to a high confidence, been verified to be clear of hazards. The route in front of the train is clear when, for the given clear distance, the SP has positively verified that:

- A clear, safe, track is present along the intended route.
- No objects present a collision hazard.
  - Verified harmless objects are not considered a hazard, e.g., an empty plastic bag is not a collision hazard, even if the train will hit it.
  - Objects with which the train may collided, and of which cannot be positively identified as a non-hazard are considered a risk.
- No conditions present a hazard within the reported clear distance.

An essential distinction between clear path detection and OOI / COI detection is the high-confidence verification that the objects present, if any, do not present a potential hazard. Checking a scene for specified OOIs, such as people and vehicles, does not preclude the possibility of other OOIs that may present a hazard. In addition, detection algorithms frequently focus on reporting the confidence that a given detection is a specific object; this is not the same as verifying that a specific object is not present. Clear path detection positively verifies the presence of a safe route.

In addition, a non-hazard of which obstructs the view (e.g., snow, falling leaves, or blown dust) will not be present in a list of OOIs as it is not, in and of itself, an OOI. Clear path detection will report the reduced clear path caused by environmental conditions and non-hazardous obstructions.

Clear path detection supports the phased development described in Section 2.6. An initial SP may be unable to distinguish between potentially hazardous and non-hazardous obstructions. Such an SP can be improved upon by adding the ability to extend the clear path past confirmed non-hazards. Such non-hazards may still limit the clear distance by obstructing the view.

2.2.2.3 Object of Interest Detection

The SP must detect and report certain objects within the foul volume and wayside as well as any potentially hazardous object with which the train may collide. An exhaustive classification of every possible object of which could enter the foul volume is not necessary. Objects only need classified to the extent to which train responses may differ, and to the extent necessary to satisfy railroad back-office reporting system needs. Objects which are verified to be non-hazards are not reported.

The list of objects which are specifically identified are:

- Person
- Vehicle
- Livestock
- Rolling Stock
- Fusee

Objects which have not been positively identified as one of the above, or as a non-hazard, are reported as "unknown – possible hazard" An object which is poses a potential hazard, is not listed above, and has been positively identified is also reported as "unknown – possible hazard" because the train response and railroad back-office reporting are the same.

2.2.2.4 Condition of Interest Detection

The SP must detect and report conditions of which pose potential hazards or otherwise require a train response (e.g., snow over rail may require brake conditioning). COIs also include the state of certain railroad equipment of which would otherwise be monitored by the train crew. The COIs which the SP must detect and report, and of which may present a hazard, are:

- Fire within the foul volume or wayside
- Earth over rail
- Water over rail
- Excessive track gauge

The COIs which the SP must detect and report, but do not present a hazard, are:

- Snow over rail
    - Each operating railroad is responsible for monitoring snow conditions and stopping trains if the snow poses a hazard.
- Crossing guard activation status
- Switch Alignment

2.2.3 SP Self-Monitoring

The SP will have some self-monitoring capabilities to detect conditions that compromise the ability of the SP to perform required functions. Conditions that may compromise the SP can be categorized as:

- Loss of communications

- Hardware failure
- Software failure
- Degraded performance

Detecting and reporting these conditions allow the train control systems to take an appropriate action to bring the train to a safe state when the SP is degraded or failed. If a condition results in the SP being unable to report its status the train control systems will detect the loss of communication with SP and handle it as a total failure of the SP.

2.2.3.1 Loss of communications

The communication link between the SP and interfaced locomotive OB subsystem(s) is monitored using a polling process. Each subsystem sends the other a regular poll message. The loss of these messages for an excessive period of time is treated as a communication failure (the exact period is TBD during subsystem & safety requirement development). If the SP stops receiving poll messages from interfaced locomotive OB subsystem(s) it will transition to a failed state. It will keep attempting to send poll messages to interfaced locomotive OB subsystem(s), but the poll messages will indicate the failure, informing interfaced locomotive OB subsystem(s)of the failure in the event that interfaced locomotive OB subsystem(s) is still receiving the poll messages.

Communication internal to the SP, such as communication between the SP and its sensors, is considered as part of the internal SP hardware monitoring.

2.2.3.2 Hardware and Software Failures

The SP must continuously monitor the ability of its internal hardware and software to perform the required functions. If a hardware or software failure results in the SP being unable to fully perform the required functionality the SP will either transition to a failed or degraded state. Designing the specifics of SP hardware and software monitoring will be at the discretion of each individual vendor, but every SP must fail such that the failure is reported to interfaced locomotive OB subsystem(s) or detected by interfaced locomotive OB subsystem(s) as a loss of communication. Vendors may add redundant hardware to improve reliability, and failures which do not compromise the performance of the SP are reported as maintenance issues not failures.

2.2.3.3 Degraded Performance

During the normal operation of the SP a situation may cause the performance of the system to become degraded but not completely inoperable. This includes but is not limited to, environmental conditions, and the malfunction of hardware. For example, dirty far field sensors may reduce the SP to only detecting OOIs and COIs in the nearfield. The SP reports degraded performance regardless to interfaced locomotive OB subsystem(s) and continues to operate to the degree it is able. The SP will continue to report degraded performance until the problem is corrected, e.g., if an obstructed sensor causes degraded performance, and the obstruction is then cleared, the SP can resume full operations and cease reporting degraded performance.

2.2.4 Interoperability

An ATO train must be able to operate across any territory of which has the proper equipment. Any qualified railroad personnel must be able to support any ATO train regardless of the owning or operating railroad. When an ATO train crosses from one territory to another it must be able to do so at track speed, without any interruption in operation or performance. To support interchange every SP must:

- Be operable by any qualified railroad personnel
- Be serviced by any qualified railroad personnel
- Meet a common set of minimum functional and performance requirements

2.3 Users and Stakeholders

The SP users and stakeholders are:

- Owning Railroad: The railroad which owns the locomotive on which an SP is installed
- Operating Railroad: Any railroad which operates an SP-equipped locomotive
- Roadway Workers:
  - Any roadway worker responsible for initializing an SP-equipped locomotive regardless of employing railroad
  - Any roadway workers responsible for servicing ATO trains
  - Any roadway workers servicing rail used by an SP-equipped locomotive or rail adjacent to rail used by an SP-equipped locomotive
- Train Crew: Any train crew personnel operating a locomotive on which an SP is installed
- The yard crew responsible for shutting down ATO trains
- The technicians responsible for installing and servicing the SP
- The general public (e.g., people at crossings, people at passenger platforms, trespassers)
- Interfaced locomotive OB subsystem(s), such as ITC-ATO Ex

2.4 Operational Description

The SP will be installed on a locomotive. The SP must operate correctly in the railroad environment without sustaining excessive damage. The SP must support line-of-road operations, running from rail yard through the intervening distance to the next rail yard. The SP must operate correctly during yard operations, pick-up of cars, drop-off of cars, and train drives. SP operations may be suspended when the locomotive is not on PTC-mapped track, and then expected to resume when the locomotive returns to PTC-mapped track.

2.4.1 Operating Concept

The SP uses sensor(s) to collect environmental data during train operations. The SP then uses dedicated hardware and software to process the data, quickly and accurately verifying the distance to which the path in front of the train is clear as well as identifying OOIs and COIs. A list of all current OOIs and COIs is maintained in the Sensor Platform Condition Dataset (SPCD). New OOIs and COIs are added to the SPCD upon detection and old OOIs and COIs are removed from the SPCD when they are no longer applicable. The SPCD records pertinent details on each OOI & COI such as classification, location, and intercept distance. The SP provides the SPCD to interfaced locomotive OB subsystem(s) to for use in train operations.

The SP may be used to support automated train operations, to support advanced remote control locomotive (RCL) application, or to supplement train crews during conventional train operations. It may also be run during conventional operations and the results simply logged; this will allow comparison of SP performance and ATO system performance, to train crew performance.

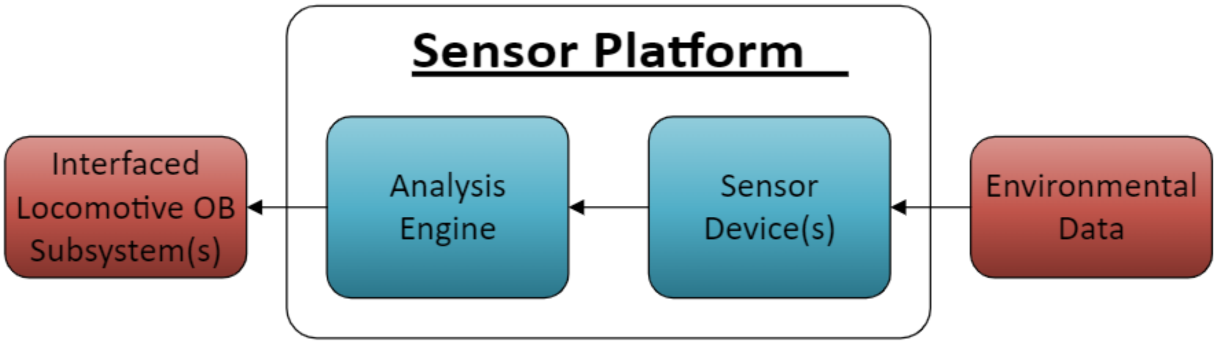

Figure A3. Sensor Platform Process Flow Diagram

2.4.1.1 Identification of AOI

As shown in Figure A2 (Section 2.2.2.1), the AOIs are the foul volume, ROW, and collision volume. Several factors must be accounted for when identifying the foul volume and wayside:

- The tracks may curve ahead of the train; the foul and wayside curve with them.
- A switch may be present; the foul and wayside are defined by the route to be taken.
  - OOIs on a diverging route must not be reported as in the foul volume unless they extend into the foul volume of the intended route.
  - The route to be taken is defined by the train's movement authority, not by observing switch positions.
- The train route may end within the sense distance of the SP.
  - It is normal for a train to come to stop at the end of a movement authority. From the SP's perspective, the end of the authority also defines the end of the foul volume and ROW. Objects beyond the end of the train's authority are not within the foul volume.
- The train route may be extended, such as when the train receives a new movement authority.
  - An OOI / COI may become applicable because the foul volume was extended when the train received a new movement authority.

The SP is provided with authoritative copies of the PTC track database, the train route, and the current position. This allows the SP to correctly identify the foul volume and ROW. While the SP may use sensory data to enhance confidence and precision of OOI / COI location, the SP may not override or ignore the foul volume as derived from the provided information.

2.4.2 Modes of Operation

The operation of the SP will require at least three modes: initialization, active, and failed. Each of these modes may be implemented using one or several states. The initialization mode includes powering on, running a power-on self-test, initializing communication with external applications, and synchronizing operational data. After completing the system initialization, the SP enters the active mode. In the active mode, the SP is continuously monitoring the external environment and providing actionable information to the external applications. If an error occurs the SP enters the failure mode. In the failure mode, the SP will either try to recover and transition back to either the initialization mode or the active mode. If the SP cannot recover it will stay in the failure mode until repaired.

The SP is not directly affected by the state of any external application(s). So long as the SP is properly initialized, can communicate with the external application(s), and receives all necessary operational data, the SP will run in active mode. How, or if, the data reported by the SP is used is out of scope for the SP.

2.4.3 Operating Environment

While the SP is installed and localized to ATO equipped locomotives, the components of the SP will have two primary operating environments. The sensor(s) used to monitor and record events will be mounted, externally, on the front of the locomotive. SP equipment located outside the locomotive will be subject to a wide range of temperatures (50°C/-40°C) and a variety of intense weather conditions, including high-speed winds, dust storms, heavy rains, hail, and snowstorms, as detailed in Table 3.1 of AAR MSRP S-9401. The sensor(s) may be installed in protective housings, or within protected locations on the locomotive, so long as they remain able to collect the required data. Complete enclosure within the locomotive body would obstruct the sensor's view of the outside environment, but climate-controlled protective housings with windows, or placement inside the locomotive cab, may be arranged as negotiated between the sensor vendor and owning railroad.

Figure A4. Example of Harsh External Environment (Image Credit AAR.org)

The SP processing unit, used to process image data and communicate with interfaced locomotive OB subsystem(s), will be located inside of the locomotive. The equipment located inside the locomotive will need to tolerate vibration and various temperatures, as detailed by AAR MSRP S-9401.

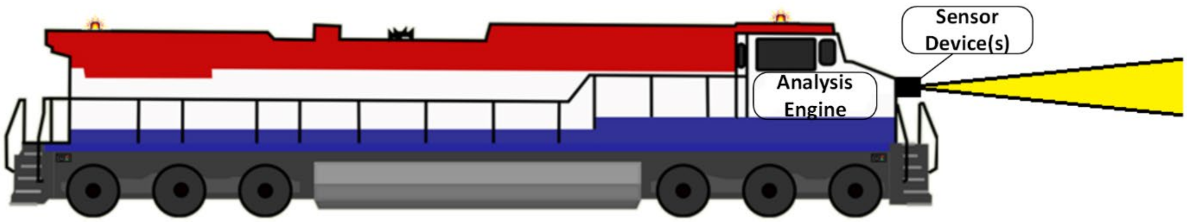

Figure A5. Sensor Platform Component Locations

2.4.4 Normal Operations

Normal operations for the SP begin when the train crew starts the train and powers on the SP. When powered on the SP automatically runs startup tests, establishes communication with interfaced locomotive OB subsystem(s), and enters a standby state. The SP transitions to an operational state when all necessary operational data has been received from interfaced locomotive OB subsystem(s), the train is on PTC-mapped track, and a valid train route has been received. An ATO train may be initialized in the yard off of PTC-mapped track in which case the SP remains in a standby state until train is moved to PTC mapped track and a train route provided.

The train can start automated operations once the ATO SoS (including the SP) has been setup, the train moved to PTC-mapped track, and the train armed. The SP will continuously run, reporting clear distance, OOIs, and COIs as the train travels its route to its intended destination. When the train reaches its destination the receiving yard workers will disengage ATO and move the train into the yard, causing the SP to return to a standby state.

The SP maintains communication with all interfaced locomotive OB subsystems throughout normal operations, which continue to provide the PTC track database, train route, and HOT position to the SP. This data allows the SP to report the clear distance along the intended train route and to map all OOI and COI detections to locations on track. The SP also provides additional information to the ITC-ATOSS BO upon request. These requests are sent via an interfaced locomotive OB subsystem.

2.4.5 System Maintenance

Routine servicing and maintenance may be performed by any railroad's qualified personnel. An SP installed by one railroad will be serviced by other railroads as the train crosses various territories. Any routine servicing and maintenance procedure must be well-documented and performed using standard tools and equipment. Examples of routine servicing and maintenance include sensor cleaning, sensor calibration (if required), configuration file updates, basic diagnostics, and simple repairs.

SP installation, major repairs, reprogramming, and reconfigurations are intended to be performed by the owning railroad. Specification of parts and techniques for major repairs are not interoperable requirements and will be at the discretion of each railroad and vender.

2.5 SP Daily Operation Overview

The day-to-day use of the SP will differ depending on the needs of the operating railroad. An example is provided here.

- **Power On**. A locomotive with a fully installed and operational OP is selected as the lead locomotive when a train is being assembled in the yard.
  - The locomotive is oriented such that the SP sensor devices have an unobstructed view of the AOIs ahead of the assembled train.
  - A roadway worker powers on the SP and other OB subsystems.
  - The roadway worker must inspect the SP prior to placing it in service, and may perform routine maintenance (e.g., cleaning the sensors)
  - The SP may be powered on before or after other OB subsystems.
- **Initialization**. Once powered on the SP automatically starts the initialization process.
  - A power-on self-test is run; this test verifies the performance of the internal computational hardware.
  - The SP establishes communication with other OB subsystems.
    - The SP will remain in a standby state until all necessary locomotive OB systems are operational.
  - The SP obtains a list of operating railroads from other OB subsystems
  - The SP provides configuration fileset summary information to other OB applications to verify that the correct filesets are loaded.
    - The SP will not complete initialization without receiving a confirmation that the loaded filesets are correct.
  - The SP synchronizes operational data.
    - The SP may enter a standby state without location data or train route but must have the PTC track database.
  - The SP runs a self-test to verify sensing capabilities.
    - All sensors must be free of obstructions for the SP to complete initialization. It will pause initialization if the sensors are obstructed and wait for the roadway worker to clean the sensors.
  - The SP has a built-in HMI that will provide basic information such as the current SP state.
- **Standby**. The SP remains in a standby state while yard operations are completed.
  - The SP must be on PTC mapped track to operate.
  - The SP will send regular status messages to interfaced OB subsystems reporting the standby state.
- **Operation**. The SP automatically enters an operational state when the yard workers move the train onto PTC mapped track. The train drives to its next stop.

- The status message provides interfaced locomotive OB subsystem(s) with the clear distance, and a list of OOIs and COIs.
- The SP constantly provides connected applications with updated the clear distance, and a list of OOIs & COIs, throughout the train's operation on PTC-mapped track.

- **Road RCL**. The train stops at an industry siding to pick up additional cars.
  - During this operation information provided by the SP serves as point protection for RCL operations
    - The operation of the SP is unchanged, and information provided is not changed, only the behavior of the connected applications changes.
  - After picking up cars the train resumes line of road operations.
- **Switch point verification**. A switch is not reporting its position via PTC. The train slowly approaches the switch and the SP reports the observed switch position.
  - This capability is always running, but the accuracy requirements are only applicable at low/stopped speeds.
- **Arrival**. The train arrives at the destination yard.
  - The SP enters a standby state when it leaves PTC-mapped track
  - Roadway workers perform any necessary maintenance on the SP
  - Roadway workers may download sensor and performance data from the SP
  - The SP is powered off

2.6 Phased Development

The SP concept supports phased implementation. The current phases are outlined as:

- Phase I: Clear Path Detection
  - Low speed operation (<20MPH) only
  - Detect a clear path as described in Section 2.2.2.2.
    - Characterization of obstructions is not performed. A non-hazard (e.g. a gigantic garden gnome) and a hazard (e.g. a person) are both characterized as potential hazards, limiting the distance to which the path can be verified as clear.
  - May support point protection during RCL operations
  - May enhance PTC protection during restricted speed operations
- Phase II: Limited operation
  - Characterize some obstructions, allowing common non-hazardous obstructions to be disregarded.
    - Detect on-route rolling stock, railroad workers, and railroad work equipment as when they are in the foul volume.
  - Operates at lower speeds (TBD speed less than 79MPH)

    - Does not detect crossing gate activation or OOIs / COIs on adjacent tracks
    - Does not detect signaling devices such as signals, flags and fusees
- Phase III: Full operation
    - All capabilities implemented
    - Works at any speed up to 79MPH
    - Supports unattended operations

2.7 SP Use cases

A set of use cases to inform SP reference development is provided here. These use cases are selected to provide an overview of SP functions and are not an exhaustive list of SP functionality.

2.7.1 Polling Process

When in an operational state the SP is continually engaged in a polling process with the interfaced locomotive OB subsystem(s) in which status messages are constantly exchanged.

Each SP status message contains a SP status information and a list of all detected OOIs/COIs. The SP status message is the primary means with which the SP provides information to the interfaced locomotive OB subsystem(s). It contains SP status information, clear distance, and the Sensor Platform Condition Dataset (SPCD). The SPCD contains a complete list of all detected OOIs and COIs; it is how detections in other use cases are reported to the interfaced locomotive OB subsystem(s). If the interfaced locomotive OB subsystem(s) stop receiving SP status messages, it assumes that the SP has failed.

The interfaced locomotive OB subsystem(s) also send status messages to the SP. These status messages are used to inform the SP of changes in operational data (See Section 2.4.4) and allow the SP to verify that all operational data is up to date.

The polling process is started as part of the initialization process and is a precondition for the synchronization of SP operational data.

Table A3. Polling Process

	Use Case: Polling Process
Trigger	Initialization process is preparing the SP for entry into an operational state
Preconditions	SP initialization has reached a point where polling is supported: • Initialization self-tests are complete • Communication with the interfaced locomotive OB subsystem(s) has been established • Interface version negotiation with interfaced locomotive OB subsystem(s) is complete
Actors	• interfaced locomotive OB subsystem(s)
Goal	SP and ITC-ATO Ex send each other constant status updates
Background Processes	• SP status monitoring • Clear path detection • OOI / COI detection

Use Case: Polling Process	
Process	**Process #1** 1) Internal timer indicates a new status message is to be sent 2) A new status message is generated using up-to-date information including: • The current SPCD (updated per OOI and COI detection) • The clear distance • The current SP status 3) SP sends the new status message to the interfaced locomotive OB subsystem(s) • The interfaced locomotive OB subsystem(s) distribute this information to other parties as needed 4) SP resets its internal status message timer 5) This process is repeated as long as the SP is operational **Process #2** (parallel to process #1) 1) SP receives a status message from an interfaced locomotive OB subsystem(s) 2) SP checks the summary information to see if all operational data is up to date. 3) SP updates any out-of-date operational data, if needed.
Termination	This use case terminates when: • The SP is shut down • The SP is transitioned to state which does not require polling • The SP has a failure of which prevents polling
Inputs	• OOI / COI detection results • Path clear detection results • Health monitoring results • Current SP state
SP Outputs	• Poll message. Includes: o Clear distance o Sight distance o SPCD (includes OOI & COI list) o SP state o SP health
Alternate Processes	**Alternate Process #1:** Process #1 Step 1: A new potential hazard is detected, causing an SP status message to be sent immediately. **Alternate Process #2:** Step 1: No SP Status message is received for TBC seconds Step 2: SP transitions to a failed state

2.7.2 OOI / COI detection

The basic use case for detection and reporting of OOIs and COIs proceeds the same regardless of the nature of the OOI / COI. See Section 2.2.2.2 for a list of the OOIs to be detected, and Section 2.2.2.4 for a list of the COIs to be detected. Specific OOIs and COIs that drive SP performance requirements are discussed later in this section and in Section 2.7.3.

Table A4. OOI / COI Detection

Use Case: OOI / COI Detection	
Trigger	An OOI / COI along the train route comes within the SP sense distance.
Preconditions	• SP is in an operational state • The train route received from an interfaced locomotive OB subsystem extends to, or past, the SP sense distance

Use Case: OOI / COI Detection	
Actors	• interfaced locomotive OB subsystem(s) • OOI / COI
Goal	OOI / COI reported to interfaced locomotive OB subsystem(s) • The interfaced locomotive OB subsystem(s) are responsible for initiating the correct train response
Background Processes	• OOI / COI detection • Polling process
Processes	1) SP detects and identifies an OOI / COI at the sense distance 2) SP reports the OOI / COI to the interfaced locomotive OB subsystem(s) 3) Train response, based on SP report, results in the appropriate train response being taken 4) SP monitors the OOI / COI and provides updated status information
Termination	This use case terminates when the OOI / COI is no longer along the train route and in front of the train.
Inputs	• Train route from interfaced locomotive OB subsystem(s) • PTC track database from interfaced locomotive OB subsystem(s) • Sensor data

SP Outputs	• List of hazards detected
	  o This is constantly updated throughout the process
	  o The OOI / COI

Alternate Processes	**Alternate Process #1:** Step 5: The train collides with the OOI Step 6: The SP reports the collision

To illustrate this use case several specific scenarios are given.

2.7.2.1 OOI / COI Detection: Trespasser Ahead of Train

Specific Scenario Trigger: As the train comes around a curve a trespasser becomes visible approximately 1000ft ahead of the train.

Process Details:

1) The SP detects and identifies the trespasser and the trespasser's location. The trespasser is in the foul volume.
2) The SP sends an updated OOI / COI list to the interfaced locomotive OB subsystem(s); this list includes the just-detected trespasser as an OOI with details including a classification of "person" and the distance to intercept.
3) The interfaced locomotive OB subsystem(s) trigger a series of horn blasts.
   a. The interfaced locomotive OB subsystem(s) may also notify the operating railroad of the trespasser.
4) The trespasser moves out of the foul volume.
5) The train proceeds safely past the trespasser.

2.7.2.2 OOI / COI Detection: Roadway Worker on Adjacent Track

Specific Scenario Trigger: The train comes within 1820ft of a roadway worker on an adjacent track.

Process Details:

1) The SP detects and identifies the roadway worker(s) and reports them as people in the ROW.
2) The interfaced locomotive OB subsystem(s) trigger a series of horn blasts and ring the bell.
3) The roadway workers remain clear of the foul volume.
4) The train rings the bell while proceeding safely past the roadway workers.
5) The roadway workers perform any duties/actions related to passing trains.
6) Once the train is past the workers the SP no longer reports people in the ROW.
7) The interfaced locomotive OB subsystems(s) stop ringing the bell.

2.7.2.3 OOI / COI Detection: Vehicle Racing Train

Specific Scenario Trigger: The train comes within sight of a distant (>1/4mile) crossing.

Process Details:

1) Prior to crossing guard activation traffic is proceeding normally through the crossing.
    a. The people and vehicles in the crossing are reported if they are in an AOI and within the sense distance. The crossing is marked in the PTC track database and the interfaced locomotive OB subsystem(s) consider the presence of a crossing, and required crossing activation time, when selecting a response to the reported people and vehicles.
2) As the train approaches the crossing, crossing guard activates
    a. People and vehicles in the crossing clear the crossing
    b. The interfaced locomotive OB subsystem(s) will now consider that crossing activation has occurred when selecting a response to any reported OOIs
3) A driver sees the crossing guard activation and starts racing the train to the crossing
4) The SP detects the vehicle and reports a predicted intercept to the interfaced locomotive OB subsystems
5) The interfaced applications take appropriate action to prevent or mitigate the predicted collision, if possible.
    a. The horn will be sounded per regulation regardless of the presence of the vehicle.
6) The driver ignores the horn blasts, bypasses the crossing protection, and attempts to cross ahead of the train.
7) The train collides with the vehicle.
8) The SP reports the collision to the interfaced locomotive OB subsystem(s).
    a. The train crew and/or interfaced locomotive OB subsystem(s) bring the train to a safe state.

b. The train crew and/or interfaced locomotive OB subsystems(s) make the necessary emergency callout.

c. The train crew and/or interfaced locomotive OB subsystems(s) report the collision to the operating railroad back office (BO).

d. The train crew and/or operating railroad takes appropriate action to notify emergency responders and resolve the situation.

9) The SP reports any damage to the interfaced locomotive OB subsystem(s).

a. When the SP is undamaged it will remain in an operational state, monitoring the environment in front of the train and reporting observed conditions (e.g., people, vehicles, and/or fires related to the collision).

b. If the SP is damaged it will transition to a degraded or failed state, and inform the interfaced locomotive OB subsystem(s) of the failure. A train crew and/or repairs will be required for train movement to resume.

2.7.2.4 OOI / COI Detection: Oncoming Train on Adjacent Track

Specific Scenario Trigger: An oncoming train on an adjacent track comes into view.

Process Details:

1) The SP detects and identifies an oncoming train on an adjacent track.
2) The SP reports the oncoming train as rolling stock in the ROW.
3) The interfaced locomotive OB subsystem(s) dim the train headlight.
4) The trains safely pass each other.
5) The SP stops reporting rolling stock in the ROW.
6) The interfaced locomotive OB subsystem(s) set the train headlight to normal brightness.

2.7.2.5 OOI / COI Detection: Identification of OOI Classified as Unknown

Specific Scenario Trigger: The SP is unable to identify an OOI in the foul volume with adequate confidence and so classifies it as unknown.

Process Details:

1) The SP detects an OOI but is unable to identify it with confidence.
2) The SP reports the OOI as unknown in the foul. The clear distance does not extend past the OOI.
3) The interfaced locomotive OB subsystem(s) initiate the appropriate train response.
   a. The most restrictive response is presumed, but selection of train responses is out of scope for this document.
4) The train moves closer to the OOI
5) The SP identifies the OOI as a non-hazard / not of interest

6) The SP stops reporting the OOI in the status message. The clear distance may extend past the location of the non-hazard.
7) The interfaced locomotive OB subsystems(s) respond to the clearing of the OOI per applicable subsystem requirements.

2.7.3 Restricted Speed

During restricted speed operations the train must be able to stop within ½ of its clear distance. The SP continually reports clear distance allowing train driving and train response processes to drive according to restricted speed rules. Specifics of the restricted speed use case that drive SP performance requirements are discussed later in this section.

Table A5. Restricted Speed

	Use Case: Restricted Speed
Trigger	The ITC-ATOSS OB starts operating a train at restricted speed • The SP does not know if a train is under restricted speed operating rules or simply operating below 20MPH. • The SP meets speed-based performance metrics regardless of if the train is operating at restricted speed or not.
Preconditions	• SP is in an operational state (fully operational or degraded) • Train is operating at restricted speed, not to exceed 20MPH
Actors	• ITC-ATO Ex • Potential hazards within the foul volume
Goal	Train can safely stop within ½ clear distance
Background Processes	• Polling process • OOI / COI detection • Path clear detection

Processes	1) A potential hazard comes into view
	2) SP detects the potential hazard
	3) SP reports the potential hazard to ATO Ex
	    • This is accomplished by the OOI / COI detection, clear path detection, and polling process.
	4) Train response and train driving processes initiate braking
	    • Response assumed for this use case; train response is out-of-scope for SP
	5) The train comes to a stop within ½ clear distance
	6) The SP continues to report up-to-date potential hazard location and clear distance
	    • Train driving processes may act as appropriate if/when the nature of the potential hazard changes.

Termination	This use case terminates when: • The potential hazard clears the foul volume, or • The train comes to a stop, or • The potential hazard is no longer on the train route.
Inputs	• Train route from ITC-ATO Ex • PTC track database from ITC-ATO Ex • Sensor data
SP Outputs	• List of potential hazards detected o This is constantly updated throughout the process
Alternate Processes	None

2.7.3.1 Track Damage and Other Hazards

Some operating conditions may result in increased risk of track damage and other hazards. This includes but is not limited to:

- Flash flood warnings (resulting in potential washouts)
- High temperature (resulting in sun kinks)
- Severe weather
  - Ice storms increasing the risk of sagging power lines
  - High winds, rain, and/or snow increasing the risk of down trees
- Track obstructions reported ahead

Per operating practices, a railroad may issue a bulletin restricting the speed of trains in the affected area. If this happens the SP is expected to detect track damage at least as reliably as a train crew, allowing the train to safely stop prior to the track damage.

2.7.3.2 Performance Metrics

Restricted speed drives a specific SP performance metric. A sight distance of 3,000ft is necessary, assuming a worst-case brake distance of 1,500ft based on a coal train descending a 1 percent grade at 20MPH.

2.7.4 Sensor Data Request

The only information constantly provided by the SP to interfaced locomotive OB subsystem(s) is the poll message, which only provides a summary of all OOIs and COIs detected. The ATO Back Office Decision Support (BODS) personnel may require additional information to resolve an exception or to support other operations. This message is sent via the ITC-ATO Back Office Server (BOS). ATO BODS personnel can request images, video, or audio information from an ATO train. ITC-ATO Ex forwards this request to the SP, and the SP provides the requested information (if available) to ITC-ATO Ex for delivery to its intended recipient.

Table A6. Sensor Data Request

	Use Case: Sensor Data Request
Trigger	ITC-ATO BOS sends a request for additional information
Preconditions	• SP is in an operational state
Actors	• ATO BODS personnel • ITC-ATO BOS • ITC-ATO Ex
Goal	ATO BODS personnel receive the requested data • SP sends ITC-ATO Ex the processed sensor data. • ITC-ATO Ex forwards information to the requesting ITC-ATO BOS.
Background Processes	• SP status monitoring • Clear path detection • OOI / COI detection
Process	1) ATO BODS personnel request sensor data for a specific train, and time or detection ID 2) ITC-ATO BOS sends the request to the proper ITC-ATO Ex which forwards it to the SP 3) The SP generates a new message using saved information including: • Raw sensor data/input regarding the detection ID • and/or sensor data at the requested time • and the identification determined for that detection ID or time 4) SP sends the message to ITC-ATO Ex 5) ITC-ATO Ex forwards the reply to the requesting ITC-ATO BOS 6) ITC-ATO BOS provides the requested information to ATO BODS personnel
Termination	ATO BODS personnel received the requested data
Inputs	• OOI / COI detection results • Path clear detection results • Health monitoring results
SP Outputs	• Sensor Data Message. Includes: o Clear distance o SPCD (includes OOI & COI list) o SP state o SP health
Alternate Processes	**Alternate Process #1** Step 3) The SP is unable to provide the requested data and instead replies with a message that the requested data is unavailable. Step 6: ITC-ATO BOS informs ATO BODS personnel that the requested information is not available.

2.7.5 SP Failure

The operation of the SP may be impaired by hardware failures, software failures, sensor obstructions, or other conditions. Operation of a train with an improperly functioning SP may result in unsafe conditions. To mitigate this hazard, if the SP becomes unable to meet the minimum interoperable requirements the SP transitions to a degraded or failed state and reports the change to interfaced locomotive OB subsystem(s.) The SP is only responsible for reporting the failure; other parts of the ITC-ATOSS OB are responsible for adjusting train operations to handle the failure. When the failure is resolved the SP will transition back to an operational state.

Table A7. SP Failure Use Case

Use Case: SP Failure	
Trigger	Any condition which impairs the ability of the SP to meet the minimum interoperable requirements. E.g.: • A hardware failure • A software failure • An obstruction (e.g., mud covering the sensors)
Preconditions	SP is in an operational state
Actors	• ITC-ATO Ex • Roadway Worker
Goal	Clear or fix the sensor(s) to get them to an operational state
Background Processes	SP monitors the external environment
Processes	1) A failure occurs 2) The failure is detected by the SP 3) SP enters a degraded or state 4) The SP reports the change in state to ITC-ATO Ex 5) The SP attempts to resolve the failure but fails. 6) The SP continues to operate in a degraded state 7) A roadway worker corrects the problem 8) SP returns to a fully operational state
Termination	The SP returns to a fully operational state
Inputs	• Health Monitoring results • Sensor data

SP Outputs	• Sensor Data Message. Includes:
	  ○ Clear distance
	  ○ SPCD (includes OOI & COI list)
	  ○ SP state
	  ○ SP health

Alternate Processes	**Alternate Process #1:** Step 4: SP successfully resolves the failure Step 5: The SP returns to a fully operational state Step 6: SP reports the change in health to ITC-ATO Ex **Alternate Process #2** Step 2: The failure prevents the SP from communicating Step 3: The failure is detected by ITC-ATO Ex as part of the polling process (see Section 2.7.1)
Related use Cases	Polling Process, Section 2.7.1

2.7.6 At-Grade Highway Crossing

When a train passes through an at-grade highway crossing the train crew is required to sound the horn and verify proper activation of the crossing protection, if present. Sounding the train horn is out-of-scope for the SP; crossing protection verification is in-scope. The track database records the type of crossing protection present at a crossing, and only crossing gate activation is verified.

People and vehicles present in an at-grade crossing prior to crossing protection activation are considered normal. The SP is a detection device and will report people in the wayside and foul volume without regard to anticipated crossing guard activation. Train response processes outside the SP may consider the presence of a crossing, and when crossing protection is designed to activate, to make train control decisions.

Table A8. At-Grade Highway Crossing

	Use Case: At-Grade Highway Crossing
Trigger	The train approaches an at-grade crossing which is on the intended route.
Preconditions	• SP is in an operational state (fully operational or degraded) • The train route received from ITC-ATO Ex indicates that the crossing is on the intended route and ahead of the train.
Actors	• Interfaced locomotive OB subsystem(s) • Vehicles • Pedestrians • Crossing guard
Goal	Crossing activation status verified and reported
Background Processes	• OOI / COI detection • Polling process

Process	1) As the trains starts approaching the crossing, pedestrians and vehicles within crossing are reported as OOIs.
	  • Train response should recognize that the crossing protection has not yet activated.
	2) Train nears crossing
	3) Crossing protection activates
	  • Pedestrians and vehicles are warned of the oncoming train both by the crossing protection and by the train horn
	4) Pedestrians and vehicles clear the foul volume
	  • Pedestrians and vehicles are reported as present in wayside, but no intercept is predicted
	5) Train passes safely through crossing
	6) Crossing protection activation is verified and reported

Termination	This use case terminates when the crossing is no longer on the train route in front of the train.
Inputs	• Train route from ITC-ATO Ex • PTC track database from ITC-ATO Ex • Sensor data
SP Outputs	• List of hazards detected o This is constantly updated throughout the process • Crossing protection activation verification
Alternate Processes	**Alternate Process #1:** Step 3: Crossing protection does not activate Step 6: Crossing protection activation failure reported. **Alternate Process #3** Step 4: Pedestrians and vehicles are not stopped and/or are not outside the foul volume (e.g. vehicle bypasses crossing protection) Step 4a: SP reports people and/or vehicles in the foul volume Step 5: SP reports collision, if applicable

2.7.7 Report Railroad Switch Position

Switch positions are normally reported to the ITC-PTC OB system by the wayside segment. However, failures in the wayside equipment can result in the ITC-PTC OB failing to receive switch positions. If this happens the train crew is responsible for manually verifying the position of the switch prior to proceeding. During automated operations, the SP must verify the position of unknown switches to allow the train to proceed. The SP will report each switch position as "normal," "reverse," "damaged/inoperable/between positions," or "unable to resolve switch position."

The current SP concept has the SP switch position verification always running to decrease the number of SP states/modes, and to decrease SP behavioral complexity. When the train is operating at low speeds (e.g., restricted speed) the SP must reliably report each switch position. When the train is operating at high speeds the switch position information will not be used, and the SP may report switches as "unable to resolve switch position" if the speed is interfering with position identification. The SP must aways meet required confidence levels when a switch is reported as being in the normal or reverse position.

The PTC track database specifies which position is normal and reverse for every switch. The SP reports switch position using normal and reverse as defined for each specific switch in the track database and does not use the appearance of the switch to define normal or reverse.

Table A9. Report Railroad Switch Position

	Use Case: Report Railroad Switch Position
Trigger	An SP-equipped train comes within sight of a switch
Preconditions	• The SP is in an operational state
Actors	• The interlocking/switch • ITC-ATO Ex
Goal	SP correctly identifies switch position and reports it to ITC-ATO Ex
Background Processes	• Polling process
Processes	1) An on-route switch comes within the SP sense distance. 2) SP references detected switch to PTC track database. 3) SP identifies switch position. 4) SP reports switch position to ITC-ATO Ex. 5) SP continues monitoring switch so long as it is visible and on-route
Termination	This use case terminates when: • The switch is no longer visible • The train route changes, and the switch is no longer on-route
Inputs	• Sensor data
SP Outputs	• Classification of switch position
Alternate Processes	**Alternate Process #1:** Step 3: SP is unable to identify the switch position Step 4: SP reports the switch ID and "unable to resolve switch position" to ITC-ATO Ex

3. SP Reference Model

The SP reference model defines the SP as a set of services. Each service is described in enough detail to understand the functionality of the service, its role in the complete SP, and its communication with other services and with external systems. The reference model is not a requirements document. Rather, it supports further development of SP requirements, allocation of SP requirements to services/subsystems, and decomposition of SP requirements into SP system elements.

3.1 Reference Model Diagram

A block diagram of the SP reference model is given in Figure A6; detailed descriptions of each service follow.

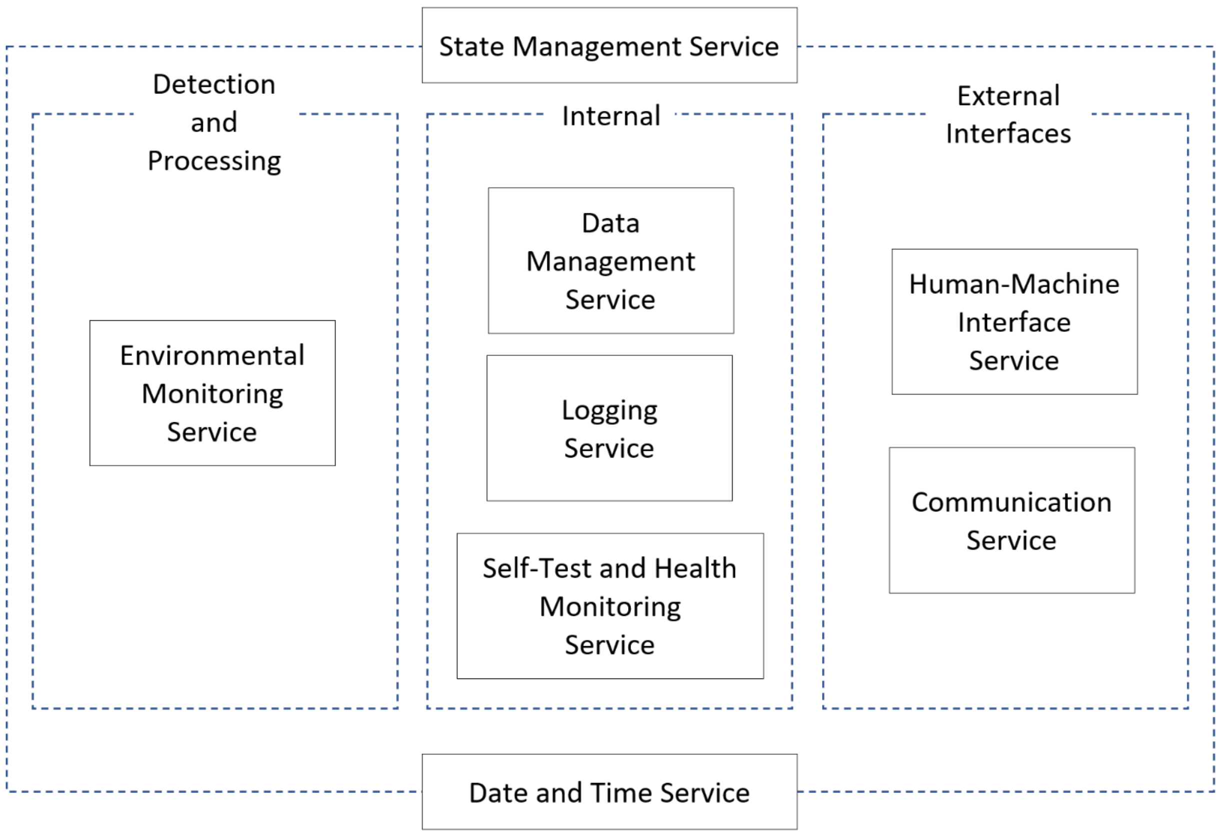

Figure A6. SP Reference Model

3.2 State Management Service

The behavior of the SP, and the requirements it meets at any given time, will depend on the state the SP is in. Detailed states will be defined in the SP Requirements documentation, but there will be at least one state for each mode of the three modes of operation given in Section 2.4.2:

- Initialization
- Operational

- Failed

As noted in Section 2.4.2, additional modes may be defined in the SP requirements documentation.

The SP requirements documentation will clearly define the functionality to be performed in each state and the state transition criteria. The state transition criteria must clearly define the state the SP is to be in at any time; they cannot allow for multiple states nor for an undefined state.

The State Management Service is responsible for monitoring the SP state transition criteria and transitioning the SP to a new state as needed. The State Management Service maintains a table of state transition criteria, and continuously compares the current values of each state transition criteria with those specified in the SP requirements. When the state transition criteria indicate a state change the State Management Service will signal all other SP services of the change in state and transition the SP to the new state. The State Management Service also monitors the state transition. If the state transition fails, the State Management Service signals the Self-Test and Health Monitoring Service and triggers a transition to a failed state.

3.2.1 Interface With Other SP Services

The State Management Service must communicate with other services to implement its functionality. At a minimum, the State Management Service is expected to communicate with other services as follows:

Input: The State Management Service receives data from all the other services to monitor the state transition criteria.

Output: The State Management Service informs all other services when a state change is required.

3.3 Date and Time Service

The date and time service performs two major functions:

- Provision of date and time to the other SP services (wall clock).
- Synchronization of time across all services and components of the SP.

3.3.1 Wall Clock

The SP is required to synchronize with the authoritative locomotive onboard point of reference for the current time which is an ITC-compliant time services as defined in S-9363. The Date and Time service handles synchronization to this service and then provides the current time to SP services as needed.

While the intent is that the Date and Time Service will be synchronized with the actual time, the SP should correctly interface and operate based on the time provided by the ITC-compliant time service. The ITC-compliant time service may or may not be synchronized with GPS time and may or may not provide the actual date and time. The SP synchronizes to the ITC-compliant time service even when the time provided is clearly incorrect. This is necessary for locomotive OB subsystems to communicate with each other when the OB time is set to something other than the actual time.

The required accuracy of time synchronization between the SP and the other locomotive OB subsystems is expected to be within the range of a few milliseconds. This accuracy will be driven by:

- Receipt and correct processing of messages between the SP and other subsystems
- Provision of accurate timestamps on OOI and COI detection

3.3.2 SP Internal Device Time Synchronization

The various SP internal components (e.g., sensors devices, analysis engines) must be synchronized to perform the necessary SP functions. For example, if several sensors are observing an OOI the data timestamp must correctly indicate when the data was collected relative to data from other sensors. Errors in the relative time between data samples may cause errors in data fusing and OOI location.

The required accuracy of time synchronization within the SP must be higher than that of time synchronization with external subsystems, likely in the range of a few microseconds. This accuracy will be driven by:

- Synchronization of data across the several sensors
- Support for stereoscopic ranging
- Support for data fusion
- The expected data sampling time and rate of possible sensor devices

Some SP designs may require precise timing pulses to synchronize the sensor devices. In such designs the Date and Time Service will be responsible for providing the timing pulses as needed.

3.3.3 Interface With Other SP Services

The Date and Time Service must communicate with other services to implement its functionality. At a minimum, the Date and Time Service is expected to communicate with other services as follows:

Input: The Date and Time Service will interface with the Communication service to receive time synchronization information from the ITC time service, as described in S-9363.

Output: The Date and Time Service interfaces with all other services as needed to provide:

- Wall clock time (accurate to a few ms)
  - Used when high precision is not necessary
- Precision time synchronization (accurate to a few μs)
- Synchronization status (reports if the Time Service is or is not currently synchronized with the ITC time service)

3.4 Self-Test and Health Monitoring Service

The self-test and health monitoring service is responsible for the detection of conditions that may impair the function of the SP. These conditions are divided into several categories:

- Environmental Conditions
- Maintenance Conditions
- Hardware Failures
- Software Failures

In addition, the severity of a condition must be characterized. Proper characterization of a condition must include:

- Is the SP still able to perform path clear verification to the required degree of accuracy?
- Is the SP still able to detect and characterize OOIs and COIs to the required degree of accuracy?
- Is the sense distance of the SP reduced?
- Does the SP need maintenance?

3.4.1 Environmental Conditions

The railroad environment contains many conditions that may degrade SP performance. These include snow, rain, fog, and obstacles obstructing visibility around curved track. Snow or other debris may prevent switch position verification and observation of track and roadbed condition. During close following moves at restricted speed rolling stock in front of the train may reduce visibility. The self-test and health monitoring service must identify if degraded performance is or is not due to environmental conditions.

3.4.2 Maintenance Conditions

A maintenance condition is a condition which the SP is not expected to resolve without outside intervention. Examples of maintenance conditions include dirty/obstructed sensors, hardware failures that do not compromise the function of the SP, and software failures that do not compromise the function of the SP.

3.4.3 Hardware Failures

A hardware failure is a condition within the SP hardware that prevents the SP from functioning correctly. This includes all SP hardware, be it computational hardware, sensors, lenses, or other SP components.

Hardware failures are categorized as:

- Degraded performance, minor repair required (may be performed by any qualified railroad personnel regardless of owning or operating railroad)
- Degraded performance, major repair required (must be performed by owning railroad or other personnel qualified for this specific SP)
- Failure, minor repair required (may be performed by any qualified railroad personnel regardless of owning or operating railroad)
- Failure, major repair required (must be performed by owning railroad or other personnel qualified for this specific SP)

Hardware monitoring will monitor the responsiveness of the sensors and other components, as well as their integrity. If the SP vendor includes built in self-maintenance functionality (e.g., sensor self-cleaning) the hardware monitoring service will activate it as appropriate and monitor success or failure.

3.4.4 Software Failures

A software failure is a condition in the SP software that compromises the functioning of the SP and cannot be automatically corrected.

Software failures are categorized as:

- Non-critical. SP may continue to function, possibly with degraded performance. Safety requirements still met.
- Critical. SP can no longer meet functional and/or safety requirements.

3.4.5 Other Self-Monitoring features

A vendor and/or railroad may add additional custom self-monitoring features to the SP as part of the self-test and health monitoring service so long as they do not compromise the required interoperable functionality. Operation of custom SP self-monitoring features is suspended when the SP is operating on a railroad which has not enabled or does not support them.

3.4.6 Failure Management

The health monitoring service must characterize all detected failures to determine:

- What is the range at which the SP is currently capable of detecting OOIs and COIs (sense distance)?
- Can the SP still meet all safety requirements?

The health monitoring service reports the results of this characterization to the State Management Service. The state management service then handles the transition to a degraded or failed state, if needed.

The Self-Test and Health Monitoring Service is also responsible for performing failure recovery tasks. Depending on the type of failure, this may include:

- Re-initializing hardware and/or software
- Prioritizing SP resources
- Activation of any self-correction features, if included by the vendor
    - e.g., a vendor may include self-cleaning devices to restore functionality when a sensor is obstructed

Upon resolution of the failure, the Self-Test and Health Monitoring Services informs the State Management and other locomotive OB subsystems of the change in SP state.

3.4.7 Interface With Other SP Services

The Self-Test and Health Monitoring Service must communicate with other services to implement its functionality. At a minimum, the Self-Test and Health Monitoring Service is expected to communicate with other services as follows:

Input: Each vendor must determine what data is necessary for health monitoring in their SP implementation. It is expected that the Self-Test and Health Monitoring Service will receive data from all other services, and from vendor-specific hardware and software modules.

Output: The Self-Test and Health Monitoring Service provides SP health information to the:

- Communication Service
  - SP health is reported to ATO Ex
- State Management Service
  - SP health is a state transition criterion

3.5 Environmental Monitoring Service

The Environmental Monitoring Service is responsible for collection of environmental data, processing environmental data, and relaying the results to other services (see Section 3.5.4). Processing of the environmental data includes recognizing COI & OOIs, assigning unique identifiers to potential hazards, categorizing OOIs & COIs, and providing clear path data. The Environmental Monitoring Service makes substantial use the PTC track database, train route, and HOT position provided by the Data Management Service to map sensor data and detections to the AOIs and HOT.

3.5.1 Data Collection

The Environmental Monitoring Service monitors the area in front of the locomotive using various sensor devices. The sensor devices are expected to produce large quantities of raw data which must be processed to identify OOIs & COIs. Raw data may also be distributed to other SP services as needed (e.g. for archival). The Environmental Monitoring Service handles all real-time processing of the sensor data; distribution of data to other services, such as the logging service, is done on a non-real-time basis.

3.5.2 Clear Path Detection

The Environmental Monitoring Service analyzes the collected data to identify the distance to which the path in front of the train along the train route is clear. Any potential obstruction is considered to end the clear path unless it has been positively confirmed to be a non-hazard.

3.5.3 OOI & COI Detection and Classification

This Environmental Monitoring Service identifies and classifies all OOIs & COIs within any AOI. Current identification types include:

- Human
- Livestock
- Vehicle

- Obstruction
- Track Damage
- Rolling Stock
- Unknown / potential hazard
- Snow, earth, or water over rail
- Fire
- Switch position
- Fusee
- Crossing protection activation status

The Environmental Monitoring Service may internally classify objects as non-hazards to support clear path detection and limitation of "unknown" objects to potential hazards. However, verified non-hazards will not be reported. When an "unknown" is verified to be a non-hazard it is simply removed from the list of OOIs reported.

3.5.4 OOI & COI Location

The Environmental Monitoring Service locates and tracks the OOIs & COIs detected in front of the train. The location of OOIs & COIs is described in terms of the train route. The location of an OOI / COI in the foul volume is simply the distance from the HOT along the train route to the OOI / COI. An OOI / COI in the ROW is reported using the distance along the train route to the closest point on track to the OOI / COI. When the exact position of an OOI / COI is not precisely known the location is reported as the shortest distance to any point within the OOI / COI's prediction interval.

3.5.4.1 OOI Tracking

The Environmental Monitoring Service tracks OOIs to predict intercept, if applicable. For example, when a trespasser is in the ROW, the Environmental Monitoring Service constantly monitors the trespasser's movement to predict if the trespasser will move into the foul volume, out of the ROW, or remaining within the ROW.

If an OOI is predicted to move into the foul such that it presents a collision hazard the potential for an intercept is reported. Both the current OOI location, and the location at which an intercept is predicted, are reported. This allows the interfaced locomotive OB subsystem(s) to distinguish between OOIs in the foul with which a collision is imminent and OOIs which a collision is unlikely. For example:

- A vehicle moving through a crossing prior to crossing guard activation will be reported when it is in the foul, but the distance to intercept will be reported as "not applicable" (because the vehicle is moving out of the crossing.
- A vehicle stuck in a crossing will be reported as a vehicle in the foul, and the distance to intercept will be reported as the distance from the HOT to the stuck vehicle. The interfaced locomotive OB subsystem(s) may consider both the predicted intercept (indicating that the

vehicle is not moving out of the crossing) and the crossing activation status when selecting a course of action.

- A vehicle moving toward a crossing prior to crossing activation may have a predicted intercept; when the vehicle slows due to crossing activation the predicted intercept will disappear. This can be distinguished from a vehicle stuck on track by the location of the vehicle, which is in the ROW, not the foul volume.
- Rolling stock stopped on the train route will be reported, and the distance to the rolling stock and the intercept distance will be the same.
- Rolling stock moving away from the train (e.g., during a following move at restricted speed) will be reported, but the intercept distance will reflect the relative train speeds.
- The clear distance reflects the distance to which the train route has been verified to be clear of obstructions and does not reflect any predicted movement of rolling stock on the train route.

3.5.5 Collision Detection

The Environmental Monitoring Service also detects collisions between the HOT and OOIs. As discussed in Section 2.2.2.1.1, any OOI which enters the collision volume is considered to have collided with the HOT. When a collision is detected, the OOI is also classified using the same classifications listed in Section 3.5.3. Collisions with OOIs are reported regardless of the level of damage to the train or to the OOI. Collisions with non-hazards (which are also not classified as OOIs) are not reported.

3.5.6 Interface With Other SP Services

The Environmental Monitoring Service must communicate with other services to implement its functionality. At a minimum, the Environmental Monitoring Service is expected to communicate with other services as follows:

Input: The Environmental Monitoring Service receives data from:

- Date and Time Service
- State Management Service
- Data Management Service

Output: The Environmental Monitoring Service provides data to:

- Communication Service
- Data Management Service
- Self-test and Health Monitoring Service
- State Management Service
- Logging Service

3.6 Communication Service

The Communication Service handles all SP external communication. The current SP concept requires the SP to communication with:

- Other locomotive OB subsystems
  - Operational data may be received from one or several OB subsystems
  - OOI / COI and status information may be sent to one or several OB subsystems
- The ITC time service
- The crash-hardened event recorder

The SP does not have a direct connection to any system not onboard the locomotive.

3.6.1 External Locomotive OB Subsystem(s)

External locomotive OB subsystem(s) send the SP:

- Regular status messages as part of the polling process
- Up-to-date train speed and position information
- A copy of the PTC track database
- SP configuration verification information
- Requests for additional information (See Section 2.7.4)

The SP provides the external locomotive OB subsystem(s) with:

- Regular status messages as part of the polling process
  - Includes OOI / COI information, see Section 3.6.2.2
- SP configuration verification information
- Replies to additional information requests

3.6.2 Polling Process

The Communication Service maintains a polling process with at least one locomotive OB subsystem (See also Sections 2.2.3.1 and 2.7.1). To support the polling process the communication service sends and receives regular status messages.

3.6.2.1 Receipt of Status Messages

The Communication Service handles receipt of regular status messages from the external subsystems. Each status message received contains summary information used by the Data Management service to check if the track database is up to date. If the Communication Service stops receiving status messages containing track data summary information, it informs the State Management Service.

3.6.2.2 Generation of Status Messages

The Communication Service generates status messages to provide regular updates to the interfaced subsystem. Each status message contains:

- SP status information

- Sense distance
- Clear distance
- Ambient temperature
- A list of all currently detected OOIs and COIs. For each OOI / COI this list includes:
    - OOI / COI classification
    - An identifier
    - Position/location information
    - Intercept information (if applicable)

The Communication Service may maintain a polling process with one or several other locomotive OB subsystems.

3.6.3 ITC Time Service

The Communication Service provides the Date and Time Service (Section 3.3) with an interface to the ITC time service. This interface must comply with S-9363. In addition, the Communication Service must not introduce delay of which compromises the ability of the Date and Time Service to properly synchronize with the ITC time service.

3.6.4 Crash-Hardened Event Recorder

The Logging Service (Section 3.7) can record logs to the Locomotive Data Acquisition and Recording System (LDARS) as needed. The Communication Service provides an S-9101C compliant interface to the LDARS, allowing the logging service to log data to crash-hardened memory as needed.

3.6.5 Interface With Other SP Services

The Communication Service must communicate with other services to implement its functionality. At a minimum, the Communication Service is expected to communicate with other services as follows:

Input: The Communication Service receives data from the:

- State management Service
- Date and Time Service
    - The Date and Time Service will require two-way communication to subscribe to the ITC time server
- Self-Test and Health Monitoring Service
    - Used to populate SP status information in the status message
- Environmental Monitoring Service
    - Used to populate OOI / COI information in the status message
- Data Management Service

  - The Data Management Service provides the contents of the SPCD to the Communications Service for transmission to the interface locomotive OB subsystem(s).
- Logging Service
  - The logging service sends data to the Communication Service for transmission to LDARS.

Output: The Communication Service sends data to:

- State Management Service
- Date and Time Service
- Self-Test and Health Monitoring Service
- Logging Service
- Data management Service

3.7 Logging Service

The logging service provides three core logging functions:

- Event logging
- System logging
- Sensor data logging
- Logging to LDARS

Logs will be stored for a TBD/TBC length of time depending on the specific information being logged and may be accessed by authorized personnel. Logging data will be recorded to different storage medium depending on the type and size of each specific log. Encryption and other data protection measures may be taken to ensure that the data cannot be improperly accessed, altered, or deleted.

3.7.1 Event Logging

The event logging functionality maintains a record of SP detection information. This may include:

- Detection event data
  - OOI / COI classification
  - Collision detections
  - Timestamp
  - Location
  - Identification information (zone detection, confidence interval, potential for collision)
- System performance and failures
- Near-detection events (potential OOIs and COIs there were not categorized as such)

- Decision-making metadata, e.g.:
    - The internal confidence assigned to a classification
    - Internal details regarding the classification process
- Clear distance and sense distance detection information

Event logs may require retention after a train drive is completed and must persist after the SP is powered off. Event logs will not need to withstand catastrophic damage to the locomotive (see Section 3.7.4 for logs that can).

3.7.2 System Logging

The logging service must provide for system logging. This includes:

- Initialization data
    - Hardware/software version data
    - Configuration version and validation information
- State transitions
    - Includes state transition criteria details
- Failure information
    - Details regarding any transition to a failed or degraded state
- SP software logs
    - Vendor-specific logs recording software operation details

System logs will require long-term retention (on the order of several months) and must persist after the SP is powered off. System logs will not need to withstand catastrophic damage.

3.7.3 Sensor Data Logging

The SP will also log some sensor data. Due to the extreme quantity of data expected from the sensor devices it may not be practical to log all sensor data for an extended period. The sensor data logging will support:

- BO information requests (see Section 2.7.4)
- Collection of information for SP performance verification and development

The logging service will be responsible for compressing the massive amounts of raw, high-resolution data generated by the sensor devices based on the owning/operating railroad configuration and available storage space. This may include storing most (or all) sensor data in a lossless format for a shorter period and storing reduced/compressed data for a longer period. Several levels of data reduction may be required. For example, the logging service might be configured to:

- Past hour: Log all sensor data in a lossless format
    - e.g., Recording lossless data from several cameras at a moderate framerate will require on the order of 50-1,000TB of storage capacity depending on camera specifics

- Past 24 hours: Log compressed sensor data at moderate fidelity
    - e.g., Recording compressed high-definition video (e.g., 1080p) for 24hours requires on the order of 1 to 10TB per camera, depending on compression level
- Past year: Log compressed sensor data at low fidelity
    - e.g., Recording compressed 480-pixel video for 1 year requires on the order of 1TB

Short-term sensor data may not need to require retention when the SP is powered off. Longer-term sensor data logs must persist after the SP is powered off. Sensor data logs will not need to withstand catastrophic damage.

3.7.4 Logging to LDARS

The Logging Service provides for logging to crash-hardened memory via the LDARS system. See S-9363 for information on LDARS. The exact data to be logged to LDARS is TBD per safety and regulatory considerations.

3.7.5 Log Retention

The Logging Service manages the retention of logs per the owning and operating railroad configurations, and with consideration of the log storage space available.

3.7.6 Interface to Other Services

The Logging Service must communicate with other services to implement its functionality. At a minimum, the Logging Service is expected to communicate with other services as follows:

Input: The logging service may receive inputs from the:

- State Management Service
- Date and Time Service
- Self-Test and Health Monitoring Service
- Environmental Monitoring Service
- Data Management Service

Output: The logging services sends data to the Communication Service for transmission to LDARS

3.8 Data Management Service

The Data Management Service will manage two sets of data necessary for interoperability:

- Configuration data
- Operational data

The configuration data contains both common and railroad-specific SP configuration files and is loaded during initialization. The operational data is situational data necessary for SP operation and is continuously updated using information provided by the interfaced locomotive OB subsystem(s).

3.8.1 Configuration Data

The configuration data contains both common and railroad specific configuration files. There will be configuration files for:

- Common configuration settings
- Owning railroad configuration settings
- Operating railroad configuration settings
    - At least one for each operating railroad, up to one per subdivision

When the train moves from one subdivision to another (and from one railroad's territory to another) the SP will switch configuration files as it crosses the subdivision boundary.

Configuration files include information such as:

- Settings for all configurable (TBC) values
- Behavioral configurations
    - e.g., livestock may be reported in some territories but not others
- Vendor-specific configuration parameters

The configuration files allow each railroad to customize the behavior of an SP to their operational and business needs.

Configuration data files are loaded to the SP per vendor and owning railroad practices and stored in non-volatile memory. During SP initialization the interfaced locomotive OB subsystem(s) sends the SP a list of the configuration files needed for the upcoming drive. The SP then replies with the current version and data integrity code each required configuration file. The interfaced locomotive OB subsystem(s) then validate the configuration files and inform the SP of the outcome. The SP cannot enter an operational state until configuration validation is complete.

3.8.2 Operational Data

The SP requires up-to-date operational data including:

- A copy of the PTC track database
- The train route
- The HOT position

The operational data listed above must be acquired from the authoritative onboard point of reference and cannot be obtained from other sources. The Data Management Service maintains up-to-date copies of each. The train route and current position are received in periodic messages. Summary information describing all necessary PTC track data files is provided in each status message. When the summary information indicates that the track data is out-of-date the Data Management Service will request up-to-date versions. The Data Management Service then provides the operational data to other SP services as needed.

3.8.3 Sensor Platform Condition Dataset

The Data Management Service maintains a list of all currently detected OOIs & COIs in the Sensor Platform Condition Dataset (SPCD) along with pertinent details for each. The Data Management Service constantly updates the SPCD with new information from the Environmental Monitoring Service. This includes adding new OOIs & COIs, removing no-longer-applicable OOIs & COIs, and updating details of each OOI & COI.

3.8.4 Interface to Other Services

The Data Management Service must communicate with other services to implement its functionality. At a minimum, the Data Management Service is expected to communicate with other services as follows:

Input: The Data Management Service receives external messages via the Communication Service.

Output: The Data Management Service provides operational data to:

- The Environmental Monitoring Service

In addition, the Data Management Service provides status information to:

- The State Management Service
- The Self-Test and Health Monitoring Service
- The Logging Service

The Data Management Service also provides the contents of the SPCD to the Communications Service for transmission to the interfaced locomotive OB subsystem(s).

3.9 Human-Machine Interface Service

Most of the SP's functionality is provided through the interface to other locomotive OB subsystems. However, a minimal direct human-machine interface will be required. The Human-Machine Interface Service provides a basic interface for roadway workers and train crew to interact with the SP, and allows workers to:

- Power on the SP
- Directly observing the state of the SP
- Download logs
- Download archived sensor data

Other functions, such as diagnosing failures and updating software, are beyond the scope of the interoperable design.

Input: The Human-Machine Interface Service does not provide data to other services.

- Powering on is performed by a switch which directly powers on the SP hardware

Output: The Human-Machine Interface Service gets data from:

- The State Management Service
- The Logging Service

4. Subsystem Allocation

The current SP concept allows the SP to be divided into an analysis engine and a sensor device subsystem. These subsystems may be developed by the same or different vendors, as determined by the operating railroad at the time of procurement.

The following allocation of SP services to possible subsystems is made to help further decompose the SP.

Table A10. SP Subsystem Service Allocation

Service	Analysis Engine	Sensor Device Subsystem
State Management	Performs full service	Does not perform any state management functions
Date and Time	Performs: • Management of time and date functions • Provision of time synchronization • Internal time synchronization	Accepts time synchronization from Date and Time Service on Analysis Engine
Self-Test and Health Monitoring	Performs full service	Provides raw sensors health data
Environmental Monitoring	Data analysis	Collects raw data
Communication Service	Performs full service	Does not perform any communication functions
Logging	Performs full service	Does not perform any logging functions
Data Management Service	Performs full service	Does not perform any data management functions. (The data management service may collect data from only some areas as directed by the Environmental Monitoring Service, but does not itself perform data management service functions as defined in Section 3.8)
Human-Machine Interface	Performs full service	May have additional power indicators (as designed by vendor and railroad)

5. Reference Documents

The following documents are referred to within the reference model.

- AAR Manual of Standards and Recommended Practices Section K2: S-9101C Locomotive Data Acquisition and Recording System (LDARS) – Event Data Acquisition Processor
- AAR Manual of Standards and Recommended Practices Section K4: S-9363 Interoperable Train Control Time and Location – Interface Control Document
- AAR Manual of Standards and Recommended Practices Section K5: S-9401 Railroad Electronics Environmental Requirements
- General Code of Operating Rules (8^{th} edition), April 1^{st} 2020
- NORAC Operating Rules (11^{th} edition), February 1^{st} 2018

Canadian Rail Operating Rules, May 9^{th} 2022