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HIGH-LEVEL APPLICATION ARCHITECTURE DESIGN FOR THE APS UPRADE*

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Abstract

A modular software platform is under active design and development for high-level applications to meet the requirements of the Advanced Photon Source Upgrade (APS-U) project. The design is based on modern software architecture, which has been used in many other accelerator facilities and has been demonstrated to be effective and stable. At APS-U, we are extending the architecture in order to efficiently commission, operate, and maintain the APS-U. Its open architecture provides good flexibility and scalability. This paper presents the current status of high-level application architecture design, implementation, and progress at APS-U.

INTRODUCTION

The control system of the Advanced Photon Source Upgrade (APS-U) adopts an EPICS-based [1] controls system standard model, which is widely used in the accelerator control community. As illustrated in Fig. 1, its three-tier controls software infrastructure consists of:

- Distributed front-end layer. This layer is often referred to as process controls of technical systems, which includes an IOC for classic technical systems like the magnet power supply, vacuum, radio frequency/low-level rf (RF/LLRF), diagnostics, and IOC for high-speed data acquisition (DAQ) technical system.
- Service layer. The service layer collects data from various sources, for example, the front-end technical controls, database, and storage; organizes the data in a predefined data structure; publishes to its upper layer and/or accepts data from its upper layer; and ships data to database or front-end systems.
- Application layer. The application on this layer often interacts with the end user through either an operator graphic interface or other software-like physics application.

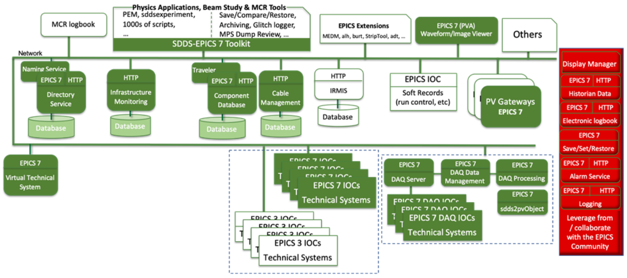

Figure 1: APS-U controls software architecture.

The high-level application (HLA) for APS-U presented in this paper is a software collection to satisfy the requirements to support APS-U engineering construction. It does not cover the physics application or the control room applications like display manager, alarm handling, data archiving, save-set-restore, etc.

HLA REQUIREMENT

To meet the APS-U project requirements, the engineer tool suite shall be modular, incrementally upgradeable, scalable, and extendable. Expansion of the tool suite to accommodate the build-up of the accelerator complex from early testing, through installation and commissioning and during the life of the facility, should not impact the performance. The tool suite shall be available to support all aspects of the project schedule from component tests during prototyping to beam characterization and optimization at commissioning and operation. To achieve this, the APS-U high-level engineering tools are required to be based on open standards and commercial off-the-shelf software applications, whenever possible.

The current Advanced Photon Source (APS) has a thorough set of tools deployed to support its operation, and most of those tools will be inherited by APS-U and/or improved upon where needed. In addition, APS-U has identified an additional set of high-level engineering tools driven by the unique requirements of the project, which are listed as below:

- Component database (CDB) [2, 3]
- Electronic traveler (eTraveler) [4, 5]
- Cable management system [3]
- EPICS directory service [6]
- Naming system
- Controls infrastructure monitoring

The latest status of those tools will be presented in this paper.

HLA STATUS

The high-level application is under active development at APS-U to satisfy the requirements of supporting project construction. Some tools have been deployed to support ongoing construction activities, and some tools are under evaluation. Detailed progress for each tool is presented in the following sections.

Component Database

The CDB manages component data and supports the full APS-U project lifecycle including both high-level and low-level design, procurement and assembly, installation and

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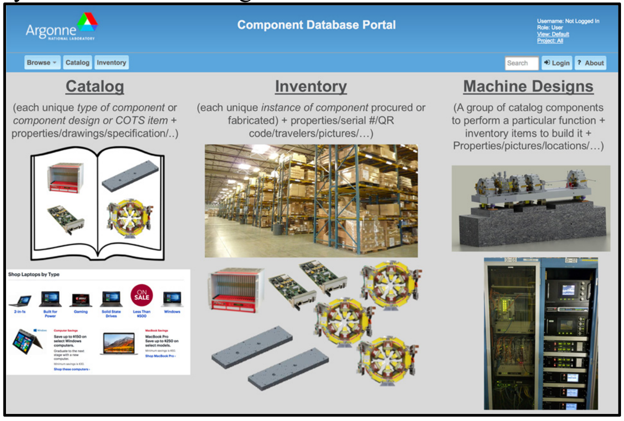
testing, and operation. It maintains a catalog of components, both purchased and fabricated, organizes documentation, and tracks component inventory location whether in storage or installed in the machine. It also facilitates creation of a high-level machine design with placeholders for the actual components. As the design evolves, items from the catalog are assigned to fulfil the roles established in the design, and eventually specific units of inventory are allocated for installation in the machine.

In the CDB vocabulary, it manages several “domains” of component information including catalog, inventory, machine design, and location, and MAARC (Measurement and Analysis Archive). Common properties (metadata) are established for items in each domain, and users may also define item-specific optional properties. A timestamped history of property values is maintained. Mini-logbooks capture chronological log entries with attachments for each item in every domain.

A web portal provides a graphical user interface to the system as shown in Fig. 2.



Component Database Portal

Username: Not Logged In
Role: User
View: Default
Project: All

Catalog

(each unique *type of component* or *component design or COTS item* + properties/drawings/specification/..)

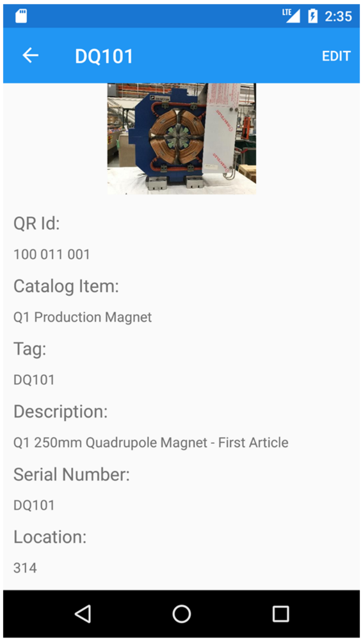
Inventory

(each unique *instance of component* procured or fabricated) + properties/serial #/QR code/travelers/pictures/…)

Machine Designs

(A group of catalog components to perform a particular function + inventory items to build it + Properties/pictures/locations/…)

Figure 2: CDB web portal.



DQ101

QR Id:
100 011 001

Catalog Item:
Q1 Production Magnet

Tag:
DQ101

Description:
Q1 250mm Quadrupole Magnet - First Article

Serial Number:
DQ101

Location:
314

Figure 3: CDB mobile application.

A REST application interface (API) has been implemented, which enables access by external programs, for example, its mobile application. The CDB mobile application has been developed to support a user’s ability to work in the field as shown in Fig. 3. A user can perform a quick task from the mobile app to check and update component location, for example, while out in the field. More implementation details are found in [2].

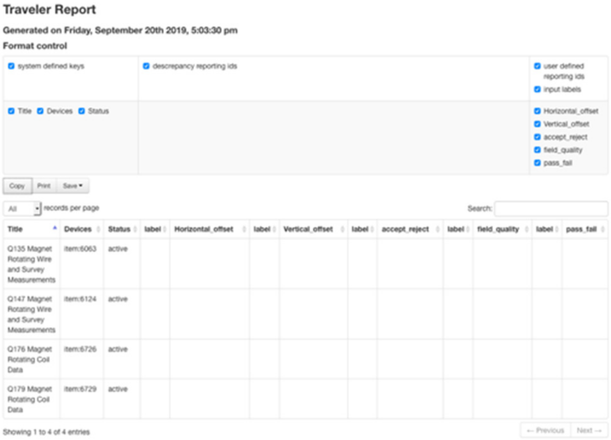
The CDB has been deployed at APS-U to actively support construction activities. It currently has more than 730 catalog items and over 2500 inventory items stored. Further enhancement is ongoing to add more features and improve its performance.

eTraveler

With modern computer technology, there is a great need to support a traveler system electronically instead of a traditional paper-based approach to assist with receiving inspection, characterization of incoming equipment, tracking accelerator component processing workflow, quality assurance inspection, recording of test results, assembly, installation, etc. At APS-U, a web-based software application, which is named eTraveler [5] and was developed originally at FRIB, was introduced. From its original version, there have been significant enhancements, which mainly include:

- Reporting
- Discrepancy
- Step numbering
- Status and version controls

The reporting function of eTraveler is implemented by introducing a reporting identifier to each input data field. When generating a report, the system categorizes user input data according to the identifier and creates a web-based table view for all selected travelers as shown in Fig. 4.



Traveler Report

Generated on Friday, September 20th 2019, 5:03:30 pm

Format control

☑ system defined keys
☑ descrepancy reporting ids
☑ user defined reporting ids
☑ input labels
☑ Title ☑ Devices ☑ Status
☑ Horizontal_offset
☑ Vertical_offset
☑ accept_reject
☑ field_quality
☑ pass_fail

All records per page

Title	Devices	Status	label	Horizontal_offset	label	Vertical_offset	label	accept_reject	label	field_quality	label	pass_fail
Q135 Magnet Rotating Wire and Survey Measurements	item:6063	active										
Q147 Magnet Rotating Wire and Survey Measurements	item:6124	active										
Q176 Magnet Rotating Coil Data	item:6726	active										
Q179 Magnet Rotating Coil Data	item:6729	active										

Showing 1 to 4 of 4 entries

Figure 4: eTraveler reporting function.

To effectively support inspection, it is important to document discrepancy properly and record all inspection results. The APS-U eTraveler system added a new traveler template dedicated for discrepancy purpose. When designing a new traveler template, the user must specify if the new template is either a regular traveler template or a discrepancy template. Designing and using a discrepancy

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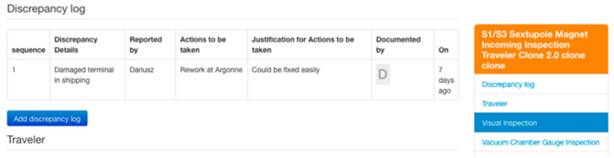
traveler is the same as a regular one except that a discrepancy traveler could be assigned and attached to a regular traveler. Once a discrepancy traveler is assigned to a regular one, a special section called "Discrepancy log" will appear on the top of the regular traveler, and all discrepancy histories will be summarized in a table view as shown in Fig. 5.



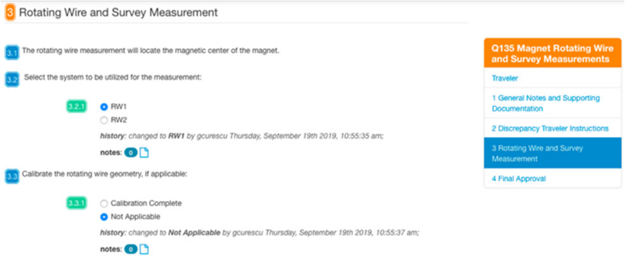
Discrepancy log

sequence	Discrepancy Details	Reported by	Actions to be taken	Justification for Actions to be taken	Documented by	On
1	Damaged terminal in shipping	Dariusz	Rework at Argonne	Could be fixed easily	D	7 days ago

Add discrepancy log
Traveler
S1/S3 Sextupole Magnet Incoming Inspection Traveler Clone 2.0 clone clone
Discrepancy log
Traveler
Visual Inspection
Vacuum Chamber Gauge Inspection

Figure 5: eTraveler discrepancy log.

The original eTraveler system supports a flat view, which is proper to support a normal daily workflow. However, to meet all needs at APS-U, especially for efficient communication between different users, a step numbering system has been implemented, which supports a hierarchical step view as shown in Fig. 6. Figure 6 shows three layers of numbering, which are the section layer (step 3), the instruction layer (steps 3.1, 3.2, and 3.3), and the data layer for user inputs (steps 3.2.1 and 3.3.1).



3 Rotating Wire and Survey Measurement

3.1 The rotating wire measurement will locate the magnetic center of the magnet.

3.2 Select the system to be utilized for the measurement:

3.2.1 ● RW1
○ RW2
history: changed to **RW1** by gcurescu Thursday, September 19th 2019, 10:55:35 am;
notes: 0

3.3 Calibrate the rotating wire geometry, if applicable:

3.3.1 ○ Calibration Complete
● Not Applicable
history: changed to **Not Applicable** by gcurescu Thursday, September 19th 2019, 10:55:37 am;
notes: 0

Q135 Magnet Rotating Wire and Survey Measurements
Traveler
1 General Notes and Supporting Documentation
2 Discrepancy Traveler Instructions
3 Rotating Wire and Survey Measurement
4 Final Approval

Figure 6: eTraveler step numbering.

The step numbers are generated by the system automatically when designing a traveler template. Once a traveler is instanced, the step numbers are fixed and are not changeable.

A discrepancy traveler template has a status, which is either draft or released. Only a released discrepancy template can be used. Currently, APS-U is actively enhancing the eTraveler system to support status for a regular traveler. Meanwhile, a mechanism to support versioning is under active development.

The eTraveler system has been deployed at APS-U and is supporting various construction activities like receiving inspection, QA inspection, and assembly. It currently has more than 160 templates and over 800 instances.

Cable

For a large-scale accelerator complex with a tight construction schedule like APS-U, managing and planning its cable is very challenging. In the nature of project construction, there are two different requirements tightly related but serving different purposes—cable management and cable raceway routing. Cable management is needed during the entire lifecycle of a project from planning to operation. Raceway and routing tools are often in high demand during construction, but they are used less frequently after the project is finished. At APS-U, to manage and plan its cable effectively through its lifecycle from planning to operation, a decision has been made to use different software for cable management and cable raceway and routing. We are planning to use a commercial COTS software [7] to manage the cable raceway and routing and to develop a cable management tool in-house by enhancing the CDB system.

To provide facilities for cable management, the CDB catalog, inventory, and machine design domains are extended by analogous domains "cable catalog," "cable inventory," and "cable design." Brief functionalities of CDB Cable are listed as below:

- Provide catalog of predefined cable types.
- Track inventory by QR ID using mobile devices.
- Facilitate evolving cable plant design, which covers high-level design using "placeholders" (e.g., rack to device) and jumpstarts the cable routing effort and endpoints later refined to the component/port level.
- Coordinate integration with the external cable routing and raceway design tool.
- Support planning and tracking of "bundles" and "dark fiber."
- Manage "virtual cables" with circuit of multiple physical cable segments.

Core CDB functionality provides component catalog and inventory tracking and machine design. The CDB Cable establishes a connection between inventory and machine design as illustrated in Fig. 7.

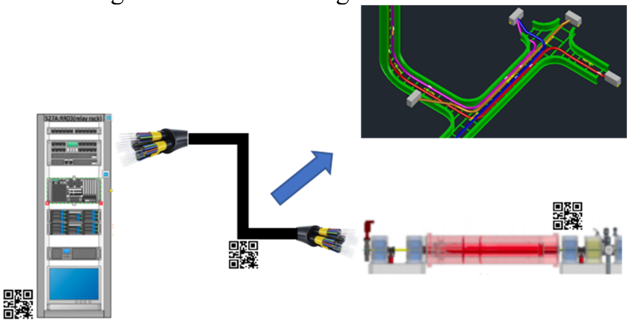


Figure 7: CDB Cable conceptual design.

It is worth mentioning that as shown in the upper-right side of Fig. 7, the cable routing is managed by our commercial COTS tool. A mechanism has been thoroughly designed to sync the data between the raceway tool and CDB Cable and is now under active development.

Another special requirement of the cable management tool is support for "virtual cables" as shown in Fig. 8. A virtual cable connects two devices, like a valve controller in a rack and a gate valve in the lattice, but there is more than one physical cable segment used to make the connection. The cable from the controller connects to the back of a patch panel, and then a different cable runs from the front of the patch panel to the valve. The real cable connections including the patch panel form a "cable circuit."

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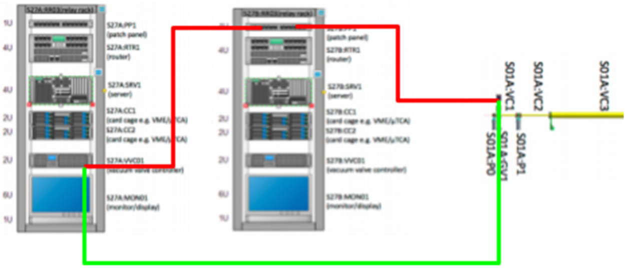
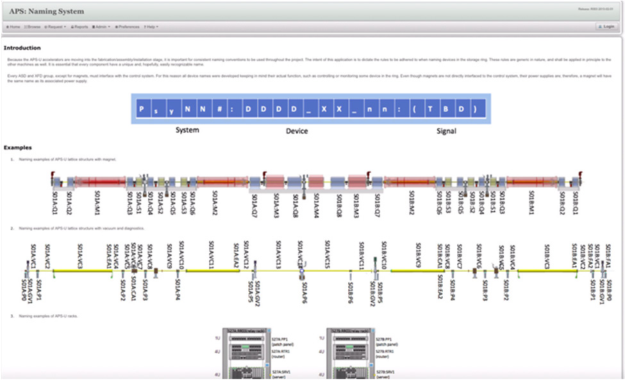


Figure 8: Virtual cable connection between the vacuum valve controller and the gate valve (green). Actual cable circuit connection via patch panel (red).

Naming

Consistent naming conventions are critical to minimize the learning curve required to effectively operate the new technical systems. For APS-U, the naming standard will provide conventions for the unique naming of devices in operation in the facility and support relational correspondence with other principle information domains for the facility. The syntax has been constructed to work within the rules and limitations of the EPICS protocol since during operation many of the devices will be actively controlled or monitored by the EPICS control system. A "naming" application shall be able to support the needs of the APS-U naming convention, and function requirements for the software have been analyzed and documented in [8].

In the accelerator control community, there are a few tools available, and each tool has most of the capabilities to meet the requirements. An evaluation is ongoing at APS-U to determine whether it is applicable and how it should be adapted to meet our needs. A particular implementation, which was originally developed in DISCS collaboration [9] and is customized to fit into the project needs, has been deployed for evaluation purposes, as shown in Fig. 9.



Introduction

Because the APS-U accelerators are moving into the fabrication/assembly/installation stage, it is important for consistent naming conventions to be used throughout the project. The intent of this application is to dictate the rules to be adhered to when naming devices in the storage ring. These rules are generic in nature, and shall be applied in principle to the other machines as well. It is essential that every component have a unique and, hopefully, easily recognizable name.

Every ASD and XFD group, except for magnets, must interface with the control system. For this reason all device names were developed keeping in mind their actual function, such as controlling or monitoring some device in the ring. Even though magnets are not directly interfaced to the control system, their power supplies are; therefore, a magnet will have the same name as its associated power supply.

Examples

1. Naming examples of APS-U lattice structure with magnet.

2. Naming examples of APS-U lattice structure with vacuum and diagnostics.

3. Naming examples of APS-U racks.

Figure 9: APS-U naming tool prototype.

EPICS Directory Service

Recent trends in the accelerator control community demonstrate a need for a hierarchical view of the control system name space. Applications often require groups of channel names related by location, technical system, or physical functions. The flat name space of EPICS is not conducive to this hierarchical concept, but a concise and thoroughly enforced naming convention assists in providing such a hierarchy with minimal functionality required within the application. The directory service provides these groups of channel names in response to a request from an application, freeing the application from explicitly specifying all of the channel names it requires. Such a service will be beneficial considering the scale, complexity, and schedule of the APS-U. The requirements for directory service have been documented in [8].

At APS, an IRMIS system [10], which was developed to support its controls system daily operation, meets some of the requirements, but it has been identified that to fully satisfy APS-U needs, significant efforts are needed to enhance IRMIS.

In the accelerator control community, there is another tool available—Channel Finder [6] —that was originally developed to support the National Synchrotron Light Source II (NSLS-II) construction and has demonstrated its value and performance.

At APS-U, we are planning to use Channel Finder as our main directory service tool to capture EPICS PVs from both EPICS 3 IOC and EPICS 7 IOC as shown in Fig. 10. Meanwhile, we will keep IRMIS to assist APS/APS-U operation until we can fully migrate its data into either the CDB or Channel Finder.

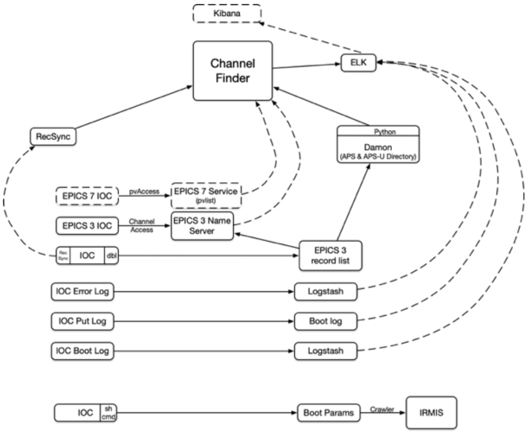


Figure 10: APS-U directory service design.

As shown in Fig. 10, because the latest Channel Finder is based on the ELK tool suite, we are planning to take advantage of its infrastructure and stream IOC log such as error log, put log, and boot log into ELK using, for example, logstash [11].

An evaluation is ongoing to determine whether this design is applicable to APS-U and how it should be adapted to meet the facility's particular needs.

Infrastructure Monitoring

Infrastructure monitoring refers to the practice of collecting regular data regarding control system infrastructure like IOCs, servers, network, etc., in order to provide alerts of unplanned downtime, network intrusion, and resource saturation, etc. Monitoring makes operational practices auditable, which is useful in forensic investigations and for determining the root cause of errors.

At APS-U, an evaluation has been conducted to compare the off-the-shelf products between Nagios, SolarWinds, and OpenNMS [12], and a decision has been made to use OpenNMS to monitor the control system infrastructure.

Based on that decision, an architecture has been designed as shown in Fig. 11.

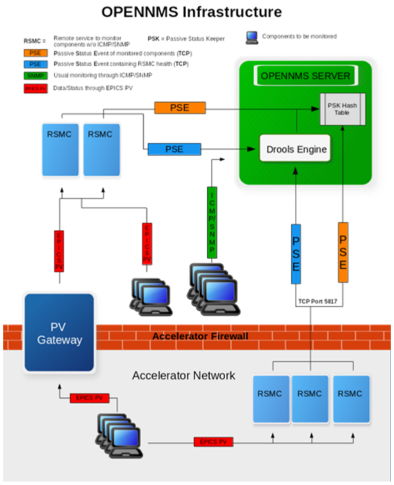

OPENNMS Infrastructure
RSMC = Remote service to monitor components w/o ICMP/SNMP
PSK = Passive Status Keeper
Components to be monitored
PSE Passive Status Event of monitored components (TCP)
PSE Passive Status Event containing RSMC health (TCP)
SNMP Usual monitoring through ICMP/SNMP
EPICS PV Data/Status through EPICS PV
OPENNMS SERVER
PSK Hash Table
Drools Engine
PSE
PSE
RSMC
RSMC
EPICS PV
EPICS PV
ICMP/SNMP
PSE
PSE
TCP Port 5817
PV Gateway
Accelerator Firewall
Accelerator Network
RSMC
RSMC
RSMC
EPICS PV
EPICS PV

Figure 11: APS-U architecture for controls system infrastructure monitoring.

SYSTEM INTEGRATION

A conceptual system integration design for high-level application, especially the database application, is illustrated in Fig. 12.

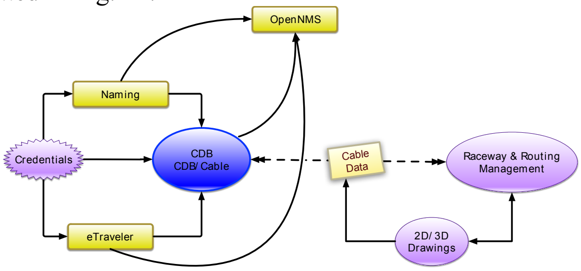
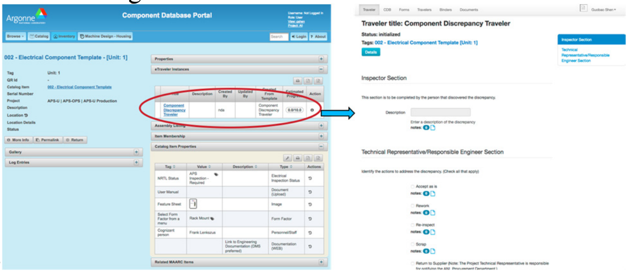


Figure 12: APS-U high-level application integration.

As discussed above, the CDB enables the application of project-wide processes, such as the establishment and enforcement of a common naming convention for components, and quality assurance and control.

Currently, the system integration has been implemented in the CDB to organize the travelers for each component as shown in Fig. 13.



002 - Electrical Component Template - [Unit: 1]

Tag: Unit: 1
QR Id: -
Catalog Item: 002 - Electrical Component Template
Serial Number
Project: APS-U | APS-OPS | APS-U Production
Description
Location
Location Details
Status

	Description	Created By	Updated By	Created From Template	Estimated Progress	Action
Component Discrepancy Traveler		nda		Component Discrepancy Traveler	0.0/10.0	

Tag	Value	Description	Type	Actions
NRTL Status	APS Inspection - Required		Electrical Inspection Status	
User Manual			Document (Upload)	
Feature Sheet			Image	
Select Form Factor from a menu	Rack Mount		Form Factor	
Cognizant person	Frank Lenkszus		Personnel/Staff	
		Link to Engineering Documentation (DMS preferred)	Documentation (WEB)	

Traveler title: Component Discrepancy Traveler
Status: initialized
Tags: 002 - Electrical Component Template [Unit: 1]

Inspector Section

This section is to be completed by the person that discovered the discrepancy.

Description
Enter a description of the discrepancy
notes: 0

Technical Representative/Responsible Engineer Section

Identify the actions to address the discrepancy. (Check all that apply)

□ Accept as is
notes: 0
□ Rework
notes: 0
□ Re-inspect
notes: 0
□ Scrap
notes: 0
□ Return to Supplier (Note: The Project Technical Respresentative is responsible for notifying the ANL Procurement Department.)

Figure 13: Organizing traveler for inventory items and link traveler instance in the CDB system.

The data between CDB Cable and the raceway routing tool are synchronized through a spreadsheet, and a template for the spreadsheet is under active development at APS-U. For the 2D/3D electrical design tool, it is able to export its drawing to import data into a raceway routing tool as well as data in the spreadsheet for importing data into the CDB Cable system.

As part of the controls system infrastructure, the system status for naming, CDB, eTraveler, etc. is planned to be monitored by OpenNMS in its production environment.

CONCLUSION

The high-level application at APS-U is a software collection to support APS-U engineering construction. To satisfy the requirements and support the project lifecycle, it has been designed to be modular, incrementally upgradeable, scalable, and extendable. A tool suite has been identified to satisfy its minimum needs. The system is under active development, and the latest status of the selected software tools is presented. Some tools, like CDB and eTraveler, have already been deployed and are actively supporting the project's construction.

ACKNOWLEDGMENT

The authors would like to thank all committee members of the APS-U CDB/eTraveler Advisory Board for their help with all aspects of software development, prompting the software use in the APS-U project, and feedback to improve the system. They also want to thank Y. Tian and Z. Yin at NSLS-II/BNL, B. Gunion at ALS-U/LBNL, and M. Dalesio and W. Lewis at Osprey for their helpful discussions on naming and their kindness in sharing their documents.

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