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Data Exchange Standard for Precision Irrigation

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ABSTRACT. *Farming has become data-driven: technology enables previously impossible levels of precision, but also burdens the grower. Data volume and complexity require the grower to spend more time processing, transforming, and understanding their operation. Further, relying on data to manage ever-larger operations amplifies the risks of bad-data-mediated errors. Growers thus need tools than can integrate the data and transform it into useful information, shifting the data management burden away from the grower and onto the software. Building these tools currently requires knowledge of agricultural operations, as well as integrating with a myriad file formats, APIs, and manufacturer-specific conventions.*

Data exchange standards can serve many purposes; two are particularly relevant here. First, standards facilitate broader (i.e., more technologies) and more comprehensive (i.e., greater level of detail and precision) systems integration. This is achieved by reducing development and maintenance costs for data handling systems. Second, standards promote reliable system interoperation: standards-compliant tools are expected to work together; the end-user benefits by having confidence that two products from difference sources will work together as expected.

The PAIL project chartered by AgGateway (a non-profit consortium dedicated to the implementation of open standards for eAgriculture) seeks to propose an open standard for irrigation data exchange (ASABE Project# X632). This paper provides an overview of PAIL deliverables. We begin by describing PAIL's overall scope. We then provide an overview of: the draft standard's division into parts; a series of business processes; core documents that support them; a set of core concepts (e.g., identity, time, reference, setup and configuration data); the relationships among those concepts; a data exchange schema; and some beta-testing conclusions. We conclude with a discussion of PAIL's impact and future direction.

Keywords. *information management. irrigation. irrigation technology. precision irrigation. standards.*

Introduction

The United Nation's Food and Agriculture Organization (FAO) has projected the earth's population will exceed 9 billion by 2050 (Alexandratos and Bruinsma, 2012). This increase will require an additional billion tons of cereal crops alone; nearly a 33% increase over current levels. The FAO expects most of the gains to come from increased yield and increased land in production. In developed countries production will increase but those gains will not come from more land allocated to production. Even with this 33% increase in production, the FAO projects that water demand will increase by only 11%. The reduced rate of increase is expected to come from improvements in water use efficiency and a reduction in rice production. Most of this increase in efficiency will come from improvements in stress tolerance and reduced water needs (Baulcombe, 2010). In developed nations, efficiency gains must come from improved management practices. In these countries, the FAO projects an 8% decrease of land in production. An increase in production demand, increase in water use, and a reduction of land all indicate that pressure on farms will continue into the future.

It is not necessary to look beyond the United States to find evidence of pressure on irrigated farms. Irrigated agriculture in the US accounts for 80-90% of the consumptive water use and approximately 40% of the value of value of agricultural production (Schaible and Aillery, 2012). This value, totaling nearly $118 billion US dollars, is produced on 57 million acres. According to the most recent Farm and Ranch Irrigation Survey (USDA, 2012) , of the 296,303 irrigated farms 25,853 reported diminished yield caused by a shortage of ground or surface water. Also of concern is than 6011 farms reported a discontinuance of irrigation, up more than 30% from the last survey.

The need for a standard

Agriculture has become a data-driven endeavor. New sources of information about soil, weather, crop status, machine operation, marketing, and economics all facilitate the evidence-based decision-making that defines precision agriculture. Using these new data streams requires tools and the evidence of this is found in the proliferation of new apps for utilizing agricultural data. A search of the Google Play store for the works "Agriculture" or "irrigation" yields 92 and 82 results respectively. Even though these tools improve accessibility of the data, the grower is responsible for relating the data to other aspects of the farm enterprise. Relating these data can involve combining multiple sources into a single output, performing calculations that transform the data in to recommended actions, or feeding models that forecast potential outcomes. Each of these tasks requires moving and transforming data. The process as a whole is integration. Each source of information has value by itself, but only when combined do they provide the evidence needed for evidence based management. In other words, integration produces decision-making power that is greater than the sum of the individual streams.

An example of integration's value is found in the study by (Wang and Cai, 2009), who examined the management benefits of incorporating weather forecasts into irrigation scheduling. In this case, the 'new' stream of data was the forecast, but providing this new product required integrating the information into an irrigation recommendation. The results of the study were what were expected: including weather forecasts improved management. However, what the growers received was more than another source of information. The researchers were integrating the forecasts into the recommendation and this integration played an important role in improving management.

Although weather data is increasingly available online, not all weather networks provide data in forms readily useable by web-based applications. For example, the Agricultural Water Conservation Clearinghouse has a list of weather stations and ET networks (Colorado State University, n.d.). Hillyer and Robinson (2010) conducted a survey of the 14 networks listed and only one (CIMIS) provided weather data in an XML format. Nearly all of the networks provide their data in a 'csv' format that is readily useable by spreadsheet applications. As of this writing, that list has grown to 25 websites or networks and seven provide data in XML or other machine-oriented format, a 4-fold increase.

Growers have long recognized the value of integration, even if not explicitly. One example of this is the Eldorado Irrigation District (EID) in northern California (Taylor, 2009). The EID has developed an irrigation management service for its members. This service includes installation and maintenance of soil and weather sensor, data entry, and a software system build specifically for the EID (TruePoint Solutions, 2008). Probably the most valuable aspect of this system is the trust that the EID has developed with its members. The growers receive irrigation recommendations via the TrueISM software and members trust the EID to do the work associated with providing the service. While a majority of the effort goes into maintaining the hardware, a significant part of the labor goes into collecting the data and moving it into the software system. Thus, a significant part of the value of this service comes from integration of sensor data, water applications, and weather information.

Many tools exist for managing irrigation (Smith et al., 2010). A majority of growers does not use physically based tools. Figure 1 shows data from Table 22 of the most recent Farm and Ranch Irrigation Survey ("Methods used in Deciding When to Irrigate") (USDA, 2012). The methods that involve evidence based management (AKA Scientific Irrigation Scheduling) are selected by 64,037 times and non-evidence based methods are selected 369,917 times. This imbalance has persisted over the last seven surveys dating back to 1988.

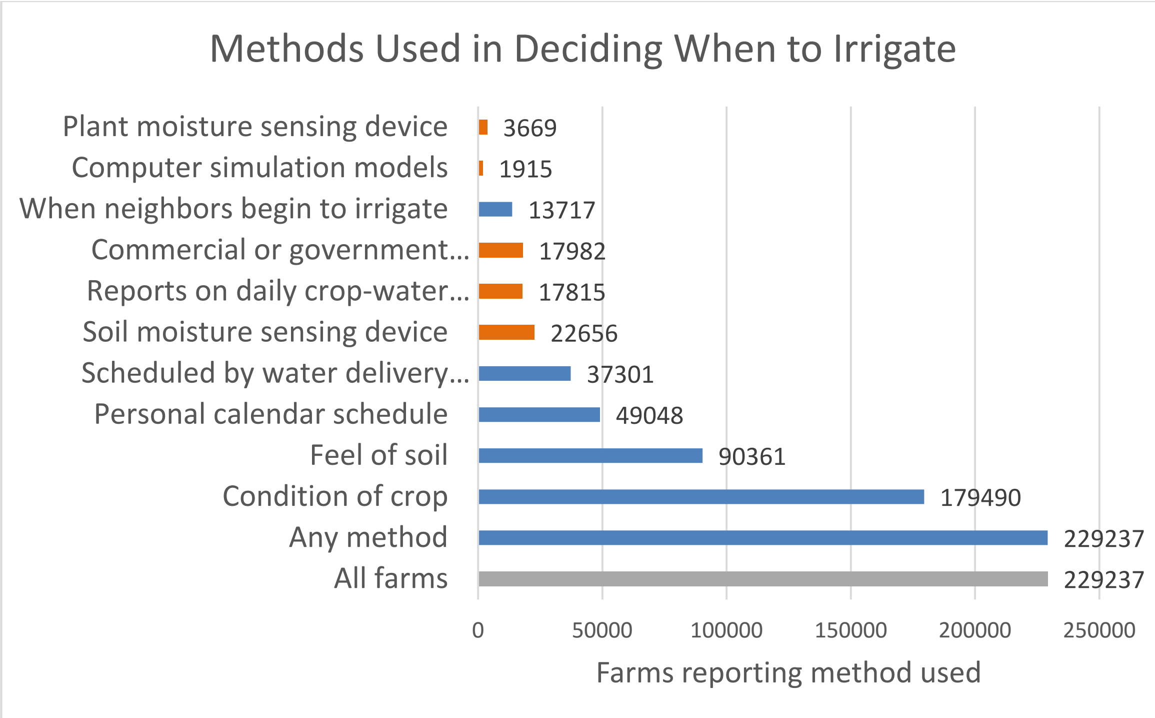


Figure 1. Table 22, Farm And Ranch Irrigation Survey, 2013 Census of Agriculture

One potential explanation for poor adoption is the effort required to use physically based methods. A soil moisture sensor can provide useful guidance about when to irrigate; in recent years, remote telemetry for soil moisture sensors has placed the data directly into the grower's hands via smartphone apps. When maximizing the value of water, however, a soil moisture sensor only tells part of the story. Growers also need to know how much water was applied, how much the crop has used, what the weather has done, and the condition of the crop. Sensors exist for each of these information sources, but only as separate tools. Maximizing the value of water requires integrating all these sources and therein lies the problem: the tools do not talk to each other. Integration is currently the grower's responsibility, and the effort required can be discouraging.

Farm Management Information Systems (FMIS) are an obvious point of integration for all these disparate information sources. By facilitating integration, an FMIS alleviates some of the grower's burden. Implementing this integration requires the FMIS to have special code to interoperate with each different data source. As new streams emerge, the FMIS must continue to expand. If each of the different tools could produce data in the same format, integration would be a simpler and thus cheaper proposition. A common data format would lower the cost of implementing integration and likely lead to a proliferation of new and more comprehensive FMIS. This proliferation would in turn lead to increased adoption of more efficient methods for deciding when to irrigate.

In the EID example above, the district's software system acts as a FMIS. In broader context, the FMIS is a central integrator because it acts as an information nexus for the farm enterprise. FMIS have been around for many years but recent changes in the ISO 11783 standard have made FMIS a central component of machine oriented agricultural operations and the data associated with them. The revised ISO 11783 standard does not include irrigation operations in any significant form.

The presence of new data sources, the multitude of existing irrigation management technology, availability of cheaper telemetry, and the expanding role of FMIS all indicate all portend an important opportunity to improve irrigation management. However, there is no established framework for integrating these disparate data sources or tools. These factors create an immediate need for an irrigation related data exchange standard. Without a data exchange standard irrigation will miss the Big Data revolution and will instead remain a "manual" management activity as evidenced by the decision preferences shown in Figure 1.

The PAIL Project

In 2011, a group of companies from the irrigation segment was brought together by the Northwestern Energy Efficiency Alliance (NEEA) to explore the development of data exchange standards for irrigation. In late 2013 development was moved into AgGateway (www.aggateway.org), a nonprofit consortium of about 240 companies dedicated to the implementation of standards for eAgriculture. This led to the chartering of the PAIL project by AgGateway's Precision Agriculture Council in early 2014.

The purpose of the PAIL project is to provide an industry-wide format that will enable the exchange and use of data from irrigation management systems. The data are currently stored in a variety of proprietary formats; the PAIL project seeks to develop a common language that can enable integration of these disparate sources of water management information.

PAIL's Objectives

PAIL covers a wide range of data, but focuses especially on two broad categories: Operations and Observations.

- **Observations** are the field, atmospheric, plant, or other *in situ* measurements that apply to irrigation management. This includes weather stations, soil moisture sensors, or crop-related sensing. This work is based on, and extends, the ISO19156 standard for observations and measurements (International Organization for Standardization, 2011).
- **Operations** are all of the activities associated with the application of water with an irrigation system. This includes, but is not restricted to, management-level communications and record keeping. The operations data set is based around a Recommendation, which describes a suggested course of action; a Work Order, which describes a desired course of action; and a Work Record, which describes what actually occurred. This work is based on, and extends, the ISO11783-10 standard for communications between agricultural machinery and FMIS (International Organization for Standardization, 2015).

Several deliverables will come from the PAIL projects. Of those, five are important for this paper.

- **User Stories** (Jeffries, 2001) **and Use Cases** (Jacobson, 1992) that describe, in a semi-structured way, the typical management scenarios where data exchange occurs. These documents effectively define the scope of the standard.
- **Process Models / BPMN Diagrams** (von Rosing et al., 2015) that represent the different processes performed by the actors in irrigation field operations. Explaining Business Process Modeling Notation (BPMN) is beyond the scope of this paper, but there are two aspects relevant to PAIL. First is that BPMNs are based on a business process, that is, the management process currently used, as seen from a farmer's perspective, whose goal is to operate as a profitable enterprise. The second element is that the process of building the BPMN results in identification of a set of messages (and data thereof) that define the communications that occur during irrigation management.
- **A field trial** (or "beta-test") that serves to expose potential conflicts or shortcomings of the standard. The trial also serves as a demonstration of the standard's value to potential adopters. The PAIL team conducted a trial during 2015 and is performing a second in 2016.
- The **XML Schema** (Fallside and Walmsley, 2004) is the primary technical deliverable. This document contains a structured and unambiguous definition of the data and how it is formatted.
- **A US National Standard**, submitted to ASABE. A standards project, X632, is already in progress in the ASABE irrigation management committee, NRES-244. Drafting of this standard is underway and submission for balloting is expected in late 2016. This ASABE standard will subsequently be submitted to the International Organization for Standardization (ISO) as a new work item proposal.

Design Goals

The PAIL team applied several guiding principles during the design process. These principles reflect the needs of the individual members of the PAIL group and support the goals of the PAIL project as a whole. At each point during the development where critical design decisions emerged, and multiple solutions were available, the design principles guided the team's decisions. The principles were not set in stone from the start of the project. Instead, they emerged as each member contributed to the development and expressed the needs of their industry segment. The principles are as follows:

Simple Beats Clever

On the surface this may seem like a different flavor of “KISS”. This intention is more subtle: when formatting data it is often possible to express the same thing in multiple ways. Some ways may be more practical for one domain than another may. There is a temptation to find a clever way to include both ways in the same data format. However, having more than one way to express the same thing creates added burden for consumers of data. Wherever possible, PAIL chose simple solutions over the ingeniously comprehensive.

Small Packets

Data relevant to irrigation travels via a variety of transport systems. Cell modem, sat-phone modem, mesh network radios, spread spectrum, radios, and direct machine-to-machine communications are all relevant. Some of these mediums (e.g. machine-to-machine via internet) have robust bandwidth capability, but many do not (e.g. sat-phone service billed by the byte). The low-bandwidth systems are just as important as the high-bandwidth, so the PAIL standard must be suitable for bandwidth-constrained applications. To that end, the schemas must minimize the size of the data packets to the greatest extent possible.

Make It Useful for the Consumer of the Data

It is often convenient for producers of data to send "everything" they have to a consumer of that data, especially if the consumer receives that data via a cloud server. However, the receiver of the data can be overwhelmed and miss the key data they need, or spend unnecessary time looking for it. When transferring data to a data consumer, the data producer should include only the reference data that is necessary for the consumer to complete their desired transaction.

JSON Friendly

The PAIL schemas are expressed as XML Schema Definition documents. This implies that all PAIL documents will be XML documents. However, while XML is a mature technology, it is not the only document formatting technology available. RESTful APIs have become the mechanism of choice for many web-based platforms. XML and JSON are, generally speaking, compatible formats but there are some ambiguities regarding how to interpret certain schema structures into JSON. AgGateway has established some guidelines to prevent these ambiguities from causing conflict when translating from XML to JSON. PAIL has followed these guidelines wherever possible.

Use Compound Identifiers

The Compound Identifier is a construct originally developed in AgGateway’s ADAPT group (AgGateway, 2016). These objects provide a locally scoped unique identifier that enables the use of objects by reference. More detail on compound identifiers is provided in the Identity section below.

Paper Overview

In this paper, we present the core elements of PAIL, the business processes those elements were derived from, and an introduction to the data structures defined in the standard. This paper will prepare the reader to begin adopting PAIL. The intended audience is both engineering research professionals who will review the standard, and practitioners who will ultimately implement the standard. This paper will enable interested persons to decide if the PAIL standard can help their organization serve the irrigation industry and, ultimately, the irrigators themselves.

Actors, User Stories, and Core Documents

Development of the PAIL data standards began by eliciting knowledge about the needs of the various **actors** in irrigation: growers, their farm staff, consultants, and service providers. We initially represented the various actors’ needs and perspectives using **user stories** (Jeffries, 2001). We also represented the data they record and exchange during irrigation operations through a set of **core documents**.

Actors

A number of people are typically involved in the planning, executing and recording of irrigation events. Of course, an individual can assume multiple responsibilities, so the actors are best seen as *persons* occupying one or more *roles*. The PAIL standard identifies these actors in Table 1 below.

Table 1. Actors in the PAIL Data Flow

Actor	Description
Grower	Has authority to make decisions for all aspects of the farm. Develops a *Crop Plan* (core document) to convey what crops will be grown, and when, on which fields. Creates *Work Orders* (core documents) out of *Recommendations* (core documents) received from the Consultant.
Consultant	Has expertise to recommend how fields should be irrigated throughout the growing season, or over multiple seasons. Reviews the Grower's *Crop Plan*. Uses data from field equipment, such as soil sensors and field weather stations, to support the recommendation process. Requests and receives data from offsite Data Providers. Integrates all relevant data to create an irrigation *Recommendation* (core document) for the Grower.
Irrigator	Performs tasks related to irrigating one or more fields; i.e., performs the actual irrigation field operation. Uses a *Work Order* (core document) received from the Grower or Consultant to initiate, run, and end an irrigation operation. May make a pre-emptive change in the work order; for example, if a rain event occurs the irrigator may suspend or halt the irrigation operation.
Data Provider	Collects, stores and makes available various forms of *Observations and Measurements* (O&M, core document) data. Collects and stores proprietary irrigation operation event data. Derives *Work Records* (core documents) from the irrigation operations event data, and makes them available to the Grower Note: more than one Data Provider could perform the tasks described above. For example, the irrigation operations data could be handled by one provider, the weather data sourced by another, and the soil water data by yet another.

User Stories

User stories provide the PAIL development team a high-level set of requirements.

Table 2. PAIL User stories

Phase	As a/an	I want to…	So that I can
Planning	Grower	create a Crop Plan	communicate my intentions for one or more growing seasons.
	Consultant	review the Crop Plan to know what crops will be planted and how they will be grown	make irrigation recommendations based on the grower's goals.
	Consultant	retrieve soil moisture, field weather and other field scouting data	integrate it into my data analysis and recommendation to the grower.
	Data Provider	retrieve, store and organize field, weather and other relevant data	send requested data to an authorized user.
	Consultant	retrieve derived weather data from a weather data service provider	integrate it into my data analysis and recommendation to the grower.
	Consultant	create a Recommendation	can advise the grower with a seasonal irrigation work plan.
	Grower	review the Recommendation from my consultant	ensure it is consistent with my farm practices and current conditions.
Execution	Grower	create an irrigation Work Order	be sure the Irrigator knows how much water to apply and where to apply it.
	Irrigator	use the irrigation Work Order to send a command to the irrigation system controller	begin and end the irrigation as planned, or modify as field conditions change.
	Data Provider	store a Work Record of what actually happened during the irrigation event	provide a record as requested from an authorized user.
Reporting	Consultant	retrieve a Work Record of the irrigation event	use the data as input for the next irrigation Recommendation.
	Grower	store and retrieve a Work Record	use it as input for planning next season's crops and field operations, and provide reports, as necessary, to regulators and/or insurance providers.

AgGateway's Core Documents for Field Operations

Growers currently face increasing pressure to document their field operations (e.g., irrigation, crop nutrition, crop protection), both for regulatory and commercial reasons. AgGateway's Core Documents for Field Operations support these activities and provide a common set of communications among Growers, Irrigators, Consultants, and Data Providers. In summary, the grower plans how to grow a crop, and then enters a cycle where observations and measurements are made about the state of the crop, an expert recommends a course of action, the grower (or an agent thereof) decides what course of action to take, the action is taken, the results are recorded, and the cycle begins anew. A grower may have a similar interest for the purposes of establishing production costs and the cost-effectiveness of specific agricultural practices.

More formally, the Core Documents (enumerated in Table 3) define data that can be exchanged during specific processes associated with a field operation. The definitions are quite flexible, in view of the myriad ways in which different growers implement their record keeping in response to regionally specific regulatory requirements, particular characteristics of their markets or farming operations, as well as personal preference.

Table 3. Core Documents

Document Name	Abbr.	Type	What It Conveys	Actor Involved
Crop Plan	Plan	Strategic	A high-level document describing how a crop will be grown on a given piece of land during a crop season. “This is how we’re going to grow this crop this season.”	Grower, or other actor involved in the strategic planning for the field operations.
Observations and Measurements	O&M	Tactical/ Predictive	A document containing data measured/observed in the field. “This is what’s happening (or what we think might happen) in the field.”	Crop scout, remote observation or a person tasked with monitoring conditions in the field.
Recommendation	REC	Tactical	"This is what I recommend we should do" This document is not always acted upon; it is acted upon via a work order, upon approval.	An individual, such as a consultant or agronomist, with the expertise / licensing necessary to recommend a course of action.
Work Order	WO	Tactical	"This is what we are going to do."	An individual with authority to order the work done.
Work Record	WR	Tactical/ Historical	"This is what we actually did in the field."	May be automatically generated; otherwise, an operator that performed the task.
Supporting Documents				
Reference Data and Setup File		All	"This is the common information we need in order to set up and support accurate and efficient data exchange."	Grower, or other actor involved in managing the grower's production data.

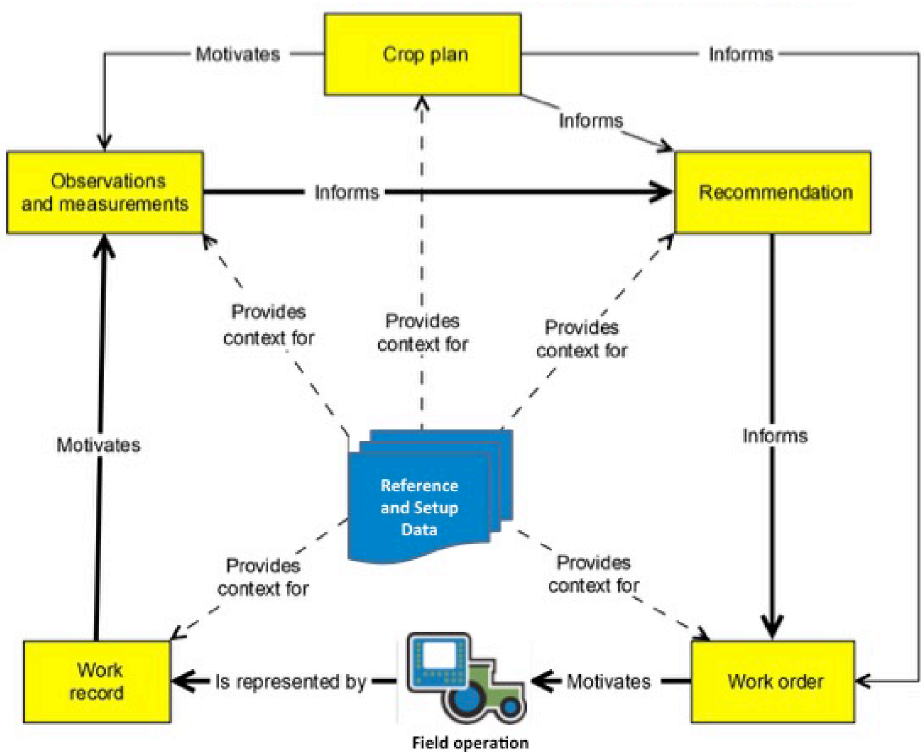


Figure 2. AgGateway Core Documents for Field Operations The diagram in Figure 2 shows the relationships among the core documents:

- The Crop Plan informs or motivates the other documents.
    - Example: a crop plan defines an irrigation water quota available to a given field; this quota informs the Recommendation of whether to irrigate or not on a given day.
- Observations and Measurements inform Recommendations.
    - Example: soil water content measurements indicating the need to irrigate.
- Recommendations inform Work Orders.
    - Example: a consultant recommends irrigating because a corn crop's anthesis will happen soon.
- Work Orders motivate Field Operations.
    - Example: A grower purchases crop protection products from a retailer and requests their application.
    - Example: A grower communicates to an operator (irrigator actor) that a field must be irrigated with a certain depth of water over a certain period of time.
- Field operations are represented by Work Records
    - Example: A telemetry system installed on a center pivot summarizes and reports data about the application of water on the field on a given day.
- Work Records motivate Observations and Measurements
    - Example: A crop scout goes out to the field to determine whether there are still symptoms of water stress in a crop following an irrigation operation.

Core Documents Flow

The previous section described the Core Documents and the relationships among them. Figure 3 shows an example of their exchange as part of the Grower's business processes:

- The Grower shares the Crop Plan with an Agronomist and an Irrigation (O&M) service.
- The Grower also shares a historical record of Work Records and O&M with the Agronomist.
- The Agronomist makes a recommendation ("Irrigation Plan") informed by the Crop Plan, the historical record, and fresh O&M.
- The Grower, informed by the Recommendation, orders a course of action through a work order ("Irrigation prescription") that is sent to the pivot panel, which executes the field operation.
- The Work Record ("Irrigation record") is returned to the grower (e.g., through a web service associated with the pivot's telemetry system.)
- The Grower processes the Work Record, creating a report shared with a regulator or value partner (e.g. a banker).

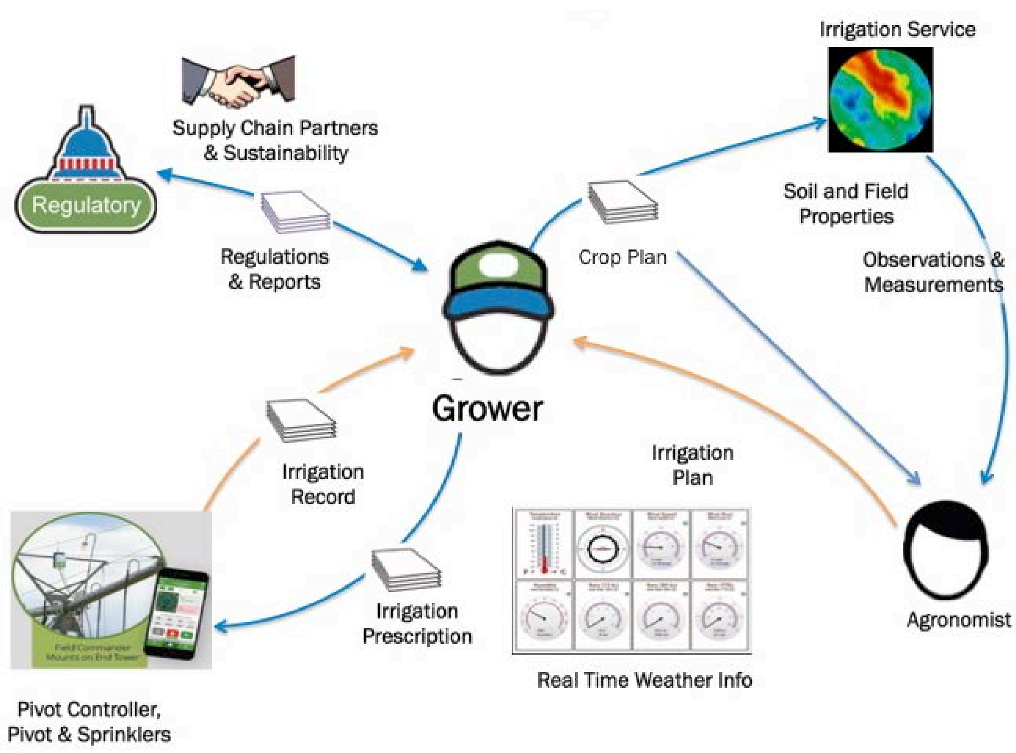


Figure 3. An example of the Exchange of Core Documents as part of a Grower's business processes.

Business Process Models

Figures 4 and 5 formalize the ideas shown above, bringing actors, Core Documents and relationships together in the context of formally specified processes. For the sake of clarity, we have placed Operations (Creation of Work Orders and Work Records) in Figure 4, and Observations (Procurement and use of O&M, Creation of Recommendations) in Figure 5.

As said earlier, a detailed description of BPMN is out of the scope of this paper. A quick introduction sufficient to understand the diagrams follows, supported by the key shown in Figure 6:

- Different actors are represented by the rectangular horizontal *pools* in the diagram.
- The processes carried out by each actor are contained in the corresponding actor's pool.
- Processes begin, end, and sometimes are paused by *events*, shown as circles in the diagrams.
- There are different kinds of events, triggered by time (shown with a clock-face icon), receiving a *message* (shown with an envelope icon), or by a *rule* being met.
- Communication among pools happens through *messages*. Note that some of those messages correspond to Core Documents.
- The flow of a process can fork, depending on the outcome of an activity. The places where flows diverge (and converges are shown with *gateways* (diamond shapes). The PAIL diagrams of Figures 5 and 6 only show a kind of gateway called "Exclusive-OR", where the divergent outcomes are mutually exclusive; i.e., only one is possible in any given situation.

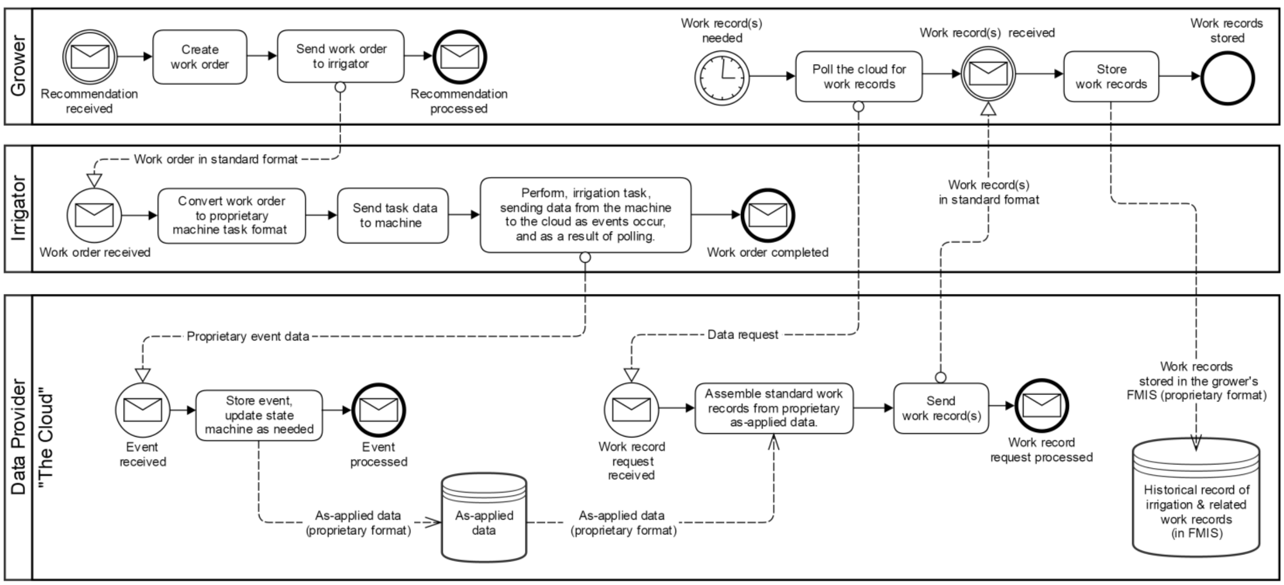


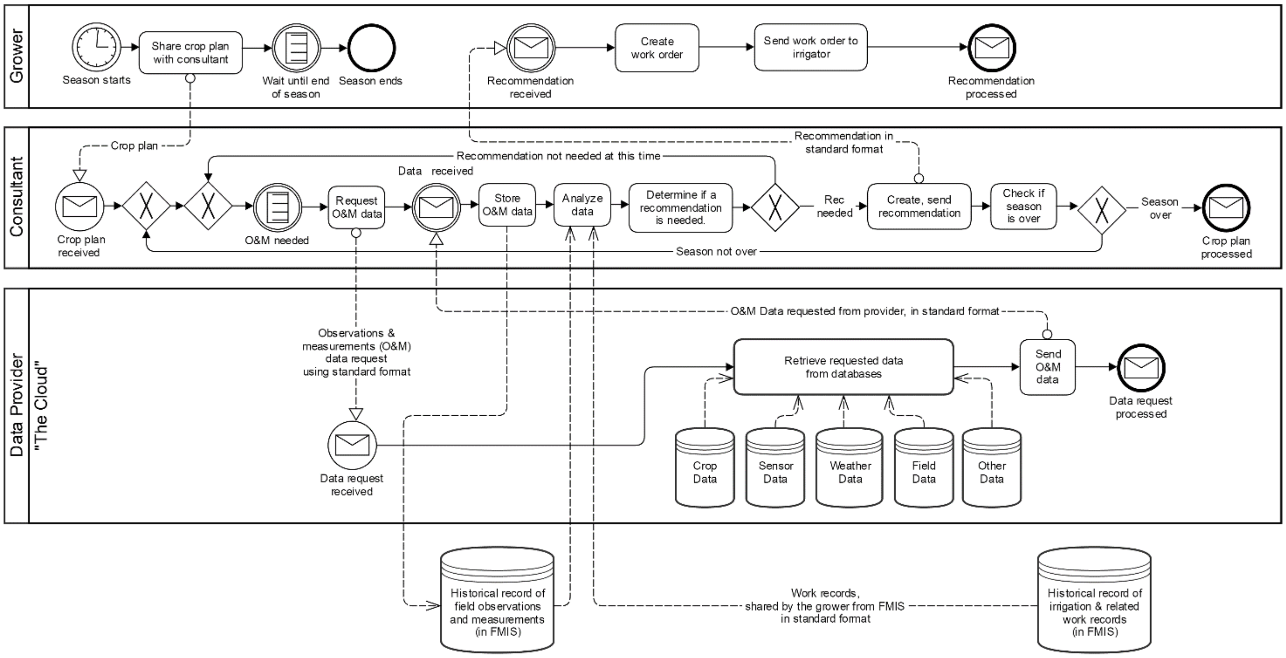
Figure 5: BPMN diagram for Operations

Figure 5 shows five different processes involved in irrigation operations:

- Grower creating a work order (from a received Recommendation) and sending it to the Irrigator.
- Grower requesting work records from a Data Provider and storing them in an FMIS.
- Irrigator executing a Work Order received from the Grower.
- Data Provider storing event data received during the execution of the field operation.
- Data Provider assembling work records from stored event data, and sending them to the Grower upon request.

Figure 6 shows three different processes involved in irrigation observations (in addition to the repeated first process above):

- Grower shares Crop Plan with Consultant, kicking off the Recommendation-creation process.
- Consultant starts season upon receipt of Crop Plan, enters a loop of requesting data from Service Provider(s), using it to create a Recommendation, and sending that to the Grower; loop executes until end of season.
- Data Provider honors requests for Observations & Measurements data.



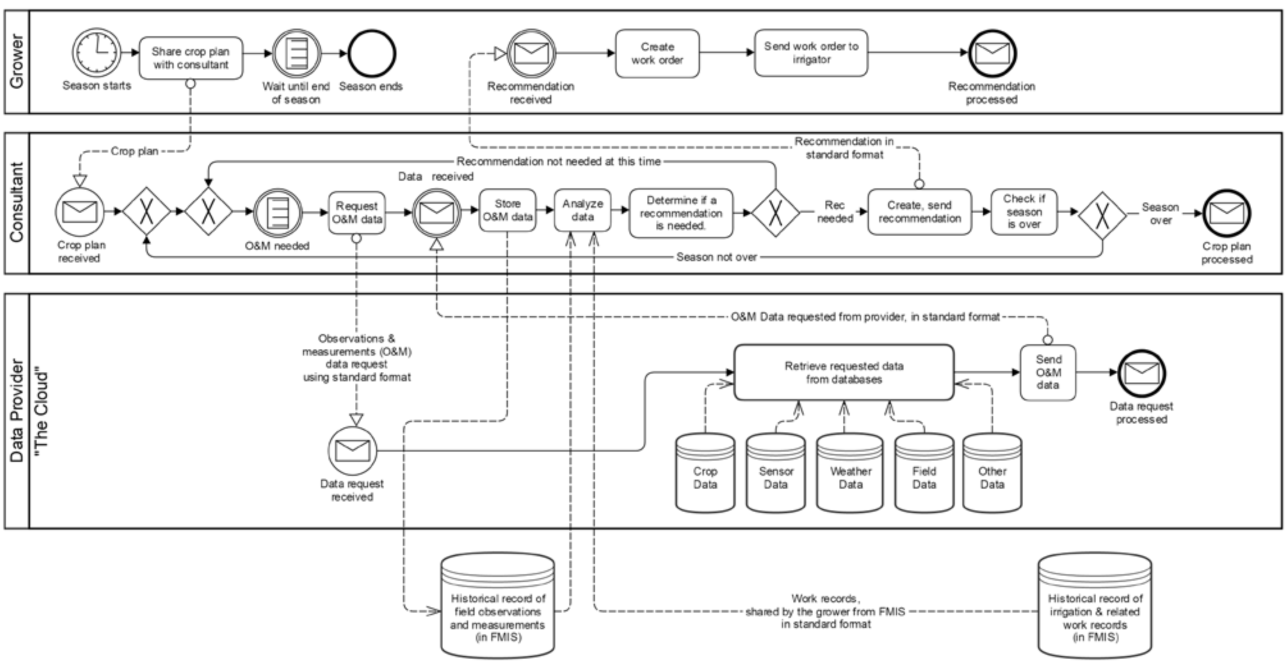


Figure 6: BPMN diagram for Observations

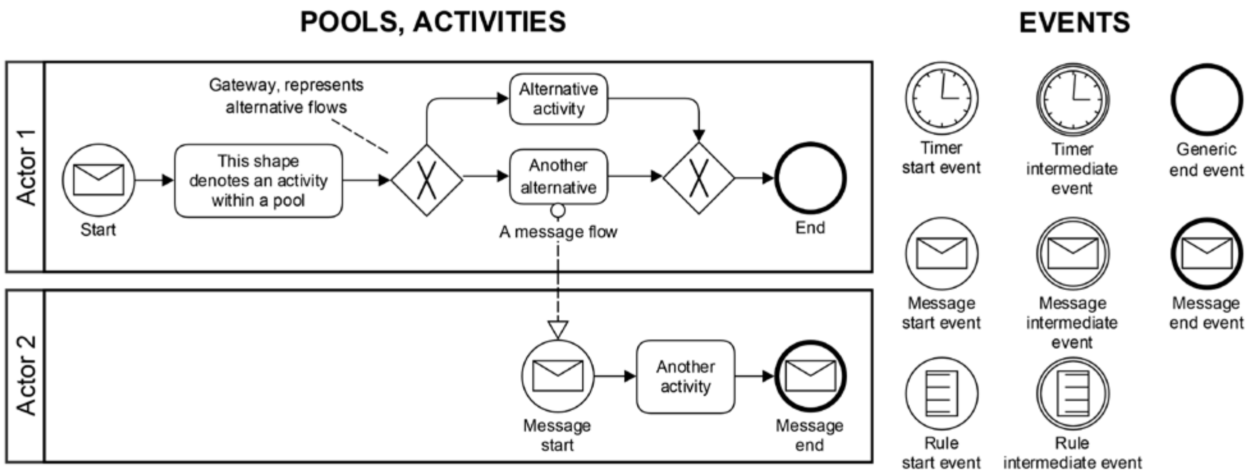


Figure 7: Key to interpret the symbols used in the BPMN diagrams shown in Figures 5 and 6.

PAIL Data: Basic Concepts

Identity

Many objects specified by the proposed PAIL standard are used *by reference* in other objects (for example, a grower, farm and field may be referenced in a work order) and thus need identifiers that can be used by the referencing object. Figure 8 shows a Unified Modeling Language (UML) class diagram (International Organization for Standardization, 2005) of the mechanism used by PAIL (and other AgGateway precision agriculture-themed standards work) to do this. It centers on an object class called CompoundIdentifier, which provides objects with a simple integer identifier (the ReferenceIdentifier) for use in the local scope of any particular instance of a data model, and allows associating an arbitrary number of (optional) unique identifiers (the list of UniqueIds) to that ReferenceId.

Each UniqueId, in turn, can be of four different types:

- A Universally Unique Identifier, or UUID (Leach et al., 2005).
- An arbitrary string (meant to accommodate proprietary alphanumeric identifiers)
- A long integer (meant to accommodate proprietary integer identifiers)
- A uniform resource identifier, or URI (W3C/IETF, 2001).

The UniqueId itself is stored as a string, but the type of UniqueId is specified with the CIType attribute.

CompoundIdentifiers are meant to be used in a distributed context, where a document may circulate among two or more FMIS. Since each FMIS may have its own set of unique identifiers (for chemical or seed products, for example), UniqueIds can specify their originating organization by populating the SourceId attribute with either a Global Location Number / GLN (GS1, 2014) or a URI. The SourceIdType attribute is specifies the type of source identifier being used.

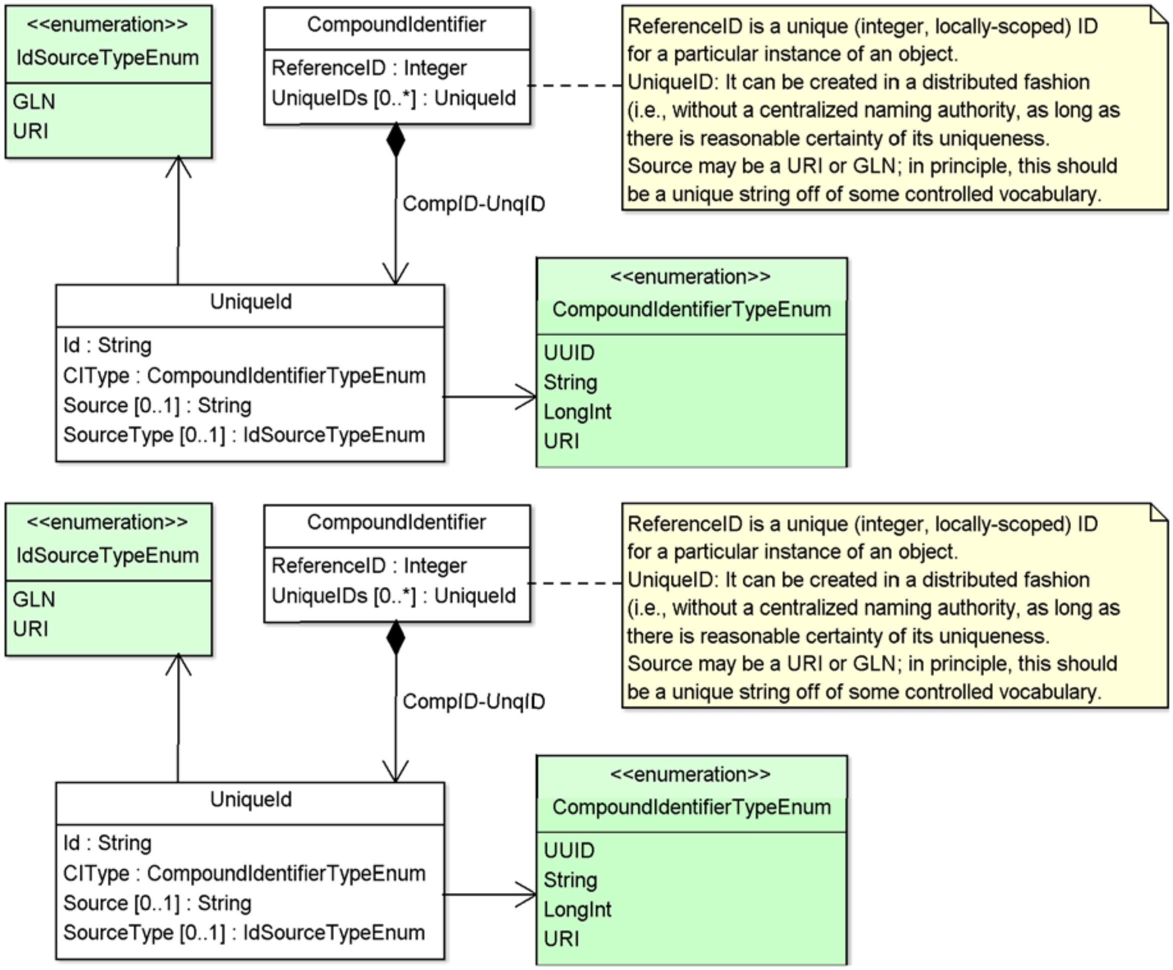


Figure 8: The CompoundIdentifier and UniqueId classes and their supporting enumerated vocabularies.

Time

Accurately capturing the time at which various events happen is an important part of agricultural record keeping. This is particularly true in irrigation, where water volumes are frequently calculated as a flow rate (e.g., in gallons per minute) multiplied by a duration. Figure 9 shows (in schema form) the mechanism used by PAIL to represent time. It is a simplification of the TimeScope used in AgGateway's ADAPT toolkit (AgGateway, 2016), and consists of two timestamps, a required Context attribute that specifies the meaning of the TimeScope through an enumerated vocabulary (not shown), and an optional human-readable Description.

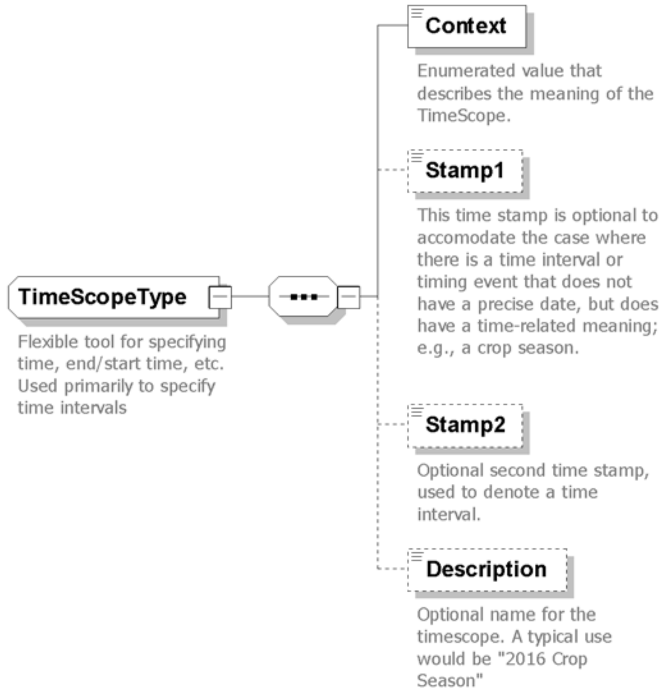


Figure 9: Representing time in the PAIL schema, with the TimeScopeType, a subset of the data available in ADAPT's TimeScope class.

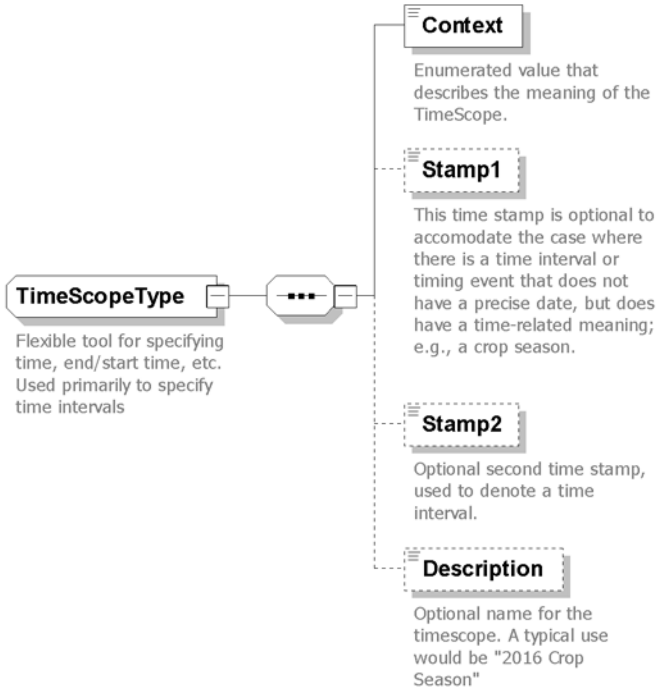
Reference, Setup, and Configuration Data

Figure 2 showed Reference and Setup Data as providing context to the Core Documents. Figure 10 explains their role in greater detail.
Reference data refers to information that a manufacturer makes available for the purchase, setup and/or use of their products, and pertains to *all instances* of a manufacturer's equipment and/or product and product components; i.e., reference data is not grower-specific or specific to an individual sale or single instance of a thing. For example, the product name, EPA number and active ingredients are reference data for a crop protection product, but a lot number is not. In another example, the model and series number are reference data for a center pivot irrigation machine, but the serial number is not.

The intent is to share reference data sets across the whole industry so that different stakeholders can interpret shared documents the same way. This includes names and identifiers of seed varieties, crop protection products, active ingredients, etc. AgGateway has several teams working to create reference data sourcing infrastructure for the industry. (AgGateway, 2015A).

Setup data provides information needed to set up data exchange between the grower and machinery or other actors (e.g., crop advisors.) It refers to two categories of information. Unlike Reference Data, Setup data is grower-specific. The two types of setup data include:

- **Grower Data** represents basic information about the grower, farm, fields, and actors. This may include farm names, field boundaries, the specific products the grower has a permit to use, etc.
- **Configuration Data** that specifies the particular state of specific instances of things such as farm equipment and instruments (e.g. soil sensors, irrigation pivots, combines, etc.) This may include their location, what they are connected to, who installed them, etc.



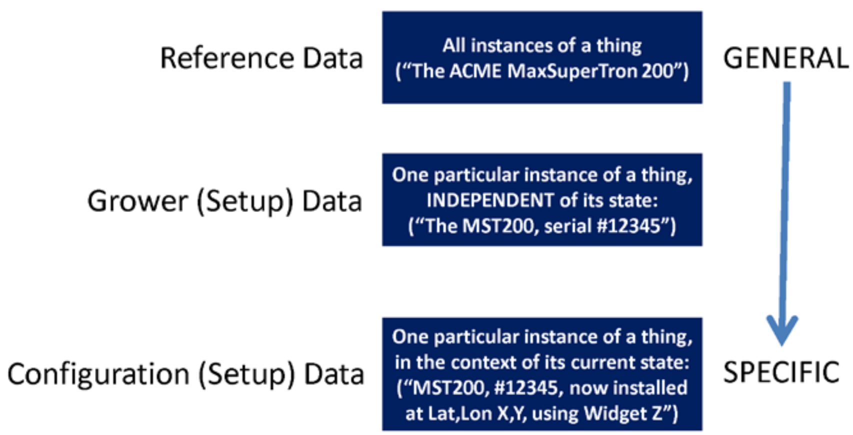


Figure 10: Reference, Setup, and Configuration Data

Figure 11 shows the relationships among different objects corresponding to Setup (Grower) Data:

- Documents can reference a Grower.
- In the context of PAIL, products are either crop protection or crop nutrition products that can be delivered through chemigation / fertigation.
- PermittedProducts mediate the (time-boxed, mediated by TimeScopes) relationship between Growers and Products. This enables the representation of what Products are available for use (for example, because the grower has a permit to use a given set of restricted-use pesticides) during a particular season. This can be useful for a situation where a grower is sharing setup data with a Consultant along with a historical record of past product applications. The grower may not have a permit to use in the current season all of the products used in the past.
- Equipment is an abstract class, a parent of irrigation equipment, sensors, etc.
- EquipmentGrower mediates the relationship between a grower and Equipment.
- Person is someone who is being recorded in the system.
- PersonRole describes a particular role being carried out by a given person, in the context of the Grower's business entity.
- Farms, Fields and Cropzones have a hierarchical relationship in the context of a Grower. They are optional as a response the ADAPT team's decision to maintain compatibility with the ISO11783 data standard (ISO, 2015).

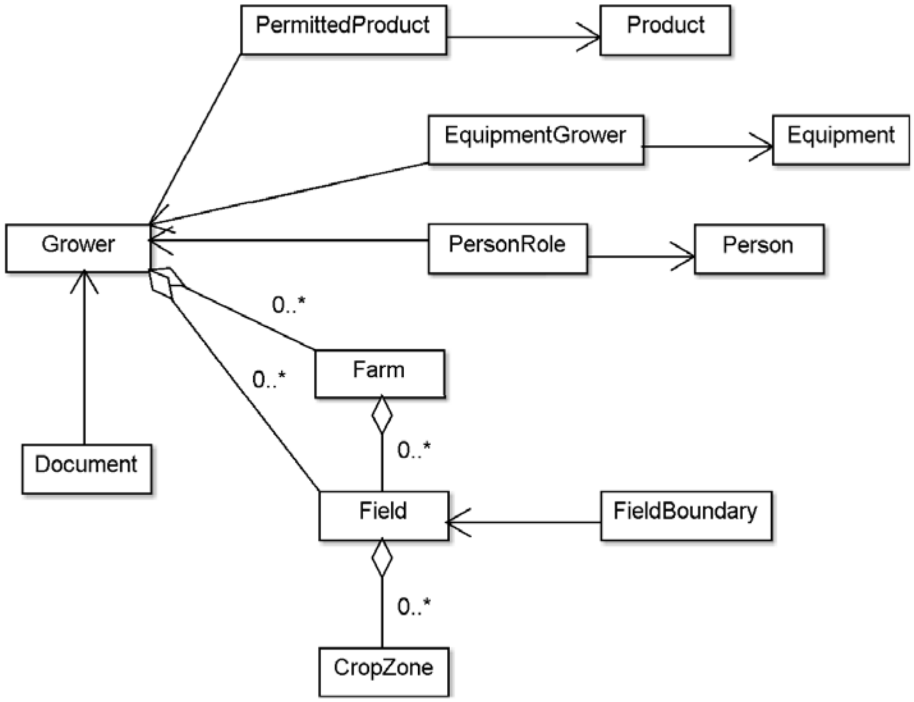


Figure 11: UML Class diagram showing PAIL implementation of Grower (Setup) Data.

Data Pedigree

In order to support the interpretation of the data being represented, the PAIL team included functionality for specifying the origin of critical information such as time and location, as well as to specify how the system providing the information represented in a data file handles setup data.

- LocationDataSource: Was the location GPS-derived? Was it obtained mechanically (e.g., through an encoder) or estimated? This is important when interpreting data from irrigation equipment such as a center pivot, where the quality assurance procedures to use for different sources of position data might vary (e.g., ensuring accurate GPS-derived positions may require trimming / removing trees that may obscure the sky near the edge of a field, whereas ensuring accurate mechanically-derived positions may require ground-truthing the accuracy of the reported azimuth of a pivot.)
- TimeDataSource: Were the recorded times derived from a GPS? Were they server-mediated when an event was uploaded by the telemetry system? This knowledge is important because the latter option is susceptible to introducing event-timing errors under conditions of telemetry system communication errors, whereas the former is not.
- SetupDataPedigree: Is the system keeping track of changes in setup data and reporting the corresponding time series of setup information along with the communicated data, or is it only keeping track of the latest setup? This has important implications for a user: in the latter case, the user would need to access data often in order to keep accurate track of changes in setup (such as the length of a center pivot) that may affect the meaning of reported data.

The intent of recording this information is not in any way prescriptive; while it is undoubtedly more convenient for a user to have the most accurate and complete options available for these kind of data, there are many legacy systems installed that produce valuable data; the purpose of the pedigree data is to provide the consumer of PAIL data files with valuable information for interpreting exchanged data.

Documents

As architected by AgGateway's SPADE (AgGateway, 2015) and ADAPT (AgGateway, 2016) teams, the five Core Documents mentioned earlier share most of their attributes, and are implemented as descendant classes of an abstract class called Document (Figure 10).

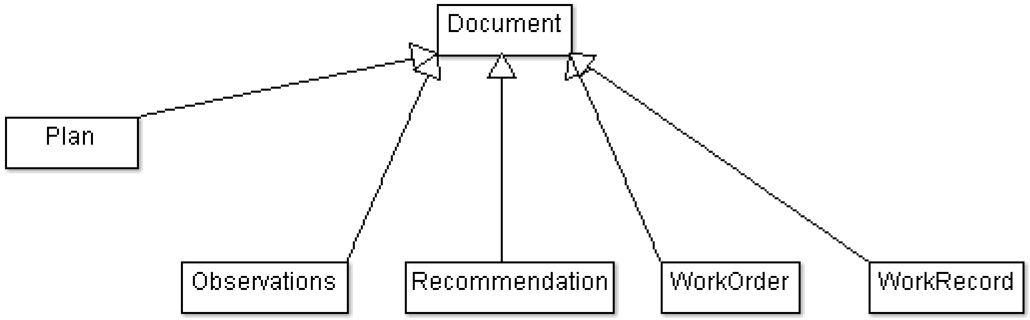


Figure 10: UML Class Diagram showing the class hierarchy of the Core Documents in ADAPT (AgGateway, 2016.)

Specific details about the different attributes in the Document-derived classes are outside the scope of this document; for the moment, it is enough to note that they answer the following questions:

- **What**: The products or services being applied, or the data being reported.
- **Where**: Grower / Farms / Fields / Cropzones / GPS locations.
- **Who**: People involved and their role: operator, agronomist, trucker, etc.
- **When**: When should / did the operation happen?
- **How**: Product rates, equipment settings, etc.
- **With What**: What equipment is involved?
- **Context items**: A generic system to encode geopolitical-context-dependent information such as (for the US) FSA, EPA, DOT numbers, harvested commodity codes and other geography-specific data that growers must track for insurance and other purposes.

Note that the actual PAIL implementation does not include the abstract Document class; consultation with developers on the team suggested that implementing the individual child classes separately in the schema (as opposed to extending a Document data type) was in line with the “simple beats clever” approach discussed earlier, and desirable for their production environments.

The Draft Standard and the Schemas

The draft standard (ASAE X632) being proposed by the PAIL team has (as of this writing) three parts (a fourth, pertaining to pumps, is in development). Each part includes an annex with a data schema covering the data presented in that part of the standard, as follows:

- Part 1: **Common elements**, meant to be used throughout the rest of the standard. Includes definitions, business process models, core concepts, product reference data, and setup data.
  - As of this writing the corresponding schema includes definitions for 23 complex XML types and 59 simple XML types
- Part 2: **Operations.** Includes Recommendations, Work orders and Work Records (Plan is out of scope of the first version); irrigation-equipment-specific reference data.
  - As of this writing the corresponding schema adds 16 complex XML types and 5 simple XML types.
- Part 3: **Observations**. Includes Observations & Measurements and its corresponding Reference (e.g., sensors, loggers, codes for features of interest) and setup data.
  - As of this writing the corresponding schema adds 9 complex XML types and 6 simple XML types.

The schemas defined in Parts 2 and 3 (and eventually 4) include the Part 1 schema, which provides them with common definitions.

Discussion

Development philosophy

The PAIL project has sought to develop a common language that enables integration of multiple, disparate sources of water management data. Working with a large variety of technology requires more expertise than any one discipline or entity can provide, so a collaborative approach was required. In “The Cathedral and the Bazaar”, Raymond (2001) describes two philosophies of software development:

- The Cathedral, essentially the traditional academic approach, where a group of experts and thinkers apply their substantial knowledge to a problem, test it, and deliver it to the expected consumers via publications, seminars, and classes. This approach has its benefits: the cathedral can produce solutions that are cohesive, clearly scoped, and well-founded in research. The disadvantage is that these solutions do not always accommodate the practical realities that practitioners must live with. This problem usually emerges from a desire to avoid complexities that would complicate an otherwise simple conceptual framework or when the complexities are caused by issues unrelated to the application domain. Those omissions are often perceived by practitioners as a lack of understanding of real-world conditions and leads to the “Ivory Tower” perception of academic solutions.
- The Bazaar, an open approach where anyone can participate (within bounds of reason). Participants are expected to contribute and the major impacts come from those that do most of the work. The Bazaar approach is messy, slow, and often contentious. However, the Bazaar has a significant advantage: the result is a product the practitioners need. The nature of participatory development means that, by the end of the development cycle, practitioners have already adopted the new system. This contrasts with the Cathedral approach, where motivating adoption is the critical and last step of the development process.

PAIL’s development has followed the bazaar model. Any corporation or individual can join AgGateway and participate in development. As of this writing, the development process has gone on for nearly three years and by the time the standard is released, there will already be several companies that have adopted the early release version. Those companies are the same ones that helped develop PAIL.

A vehicle for research

PAIL can also provide value to the research community. Many decision-support system (DSS) tools are developed by researchers with the intention of providing growers with an easier way to implement robust management practices. These DSS incorporate advanced analytical methods and often include field validation that demonstrates their potential for resource conservation, improved efficiency, or greater profitability. A problem is that the tool itself, however, is typically written by a graduate student whose field of study is not interface design or software engineering, and who does not necessarily use robust industry standard practices for software development. This becomes an obstacle to industry adoption. Additionally, when the student graduates development stops and does not continue unless the principal investigators can find additional funding. The implication of this is that often the DSS will “sit on a shelf collecting dust”, be perceived as no longer in active development, and be abandoned by the users.

Grant-driven research is not an optimal framework for maintaining applied, production oriented software. That type of tool requires customer support, continual debugging, and a commitment to evolving the software as customer’s needs evolve. Commercial development is geared towards those needs and software companies are successful because they provide those services effectively.

Standardized interoperability provides a means for researchers to deliver research products, in the form of DSS, without the burdens associated with maintenance and customer support. The DSS tools can be written to interact with the interfaces or data formats defined by the PAIL standard, freeing the researchers (and the graduate students) from the need to build, maintain and support a “user friendly” interface. Instead, companies can integrate the DSS into their products and focus on providing the user interface and customer support that they are successful at providing. Thus, the PAIL standard is a means to deliver the benefits of research to growers without the burden of continually requiring funding to support maintenance.

There is another research-oriented aspect that is an indirect consequence of the bazaar model of development: the companies that drive PAILs development are focused on providing services that are needed now or will be in the near future. To be useful, the standard must be relevant to current practices. Research, on the other hand, is focused on developing new methods, which may require data or concepts not yet in use by industry. Because the standard is focused on current practice, it could conceivably not have sufficient constructs to express the new methods. Significant effort was made to develop a standard that is generic enough to avoid these conflicts but no standard can account for every eventuality. When researchers encounter a situation where a new method cannot be expressed in PAIL, this is an indirect indication of a significant incompatibility with current practices. Such conflicts will motivate researcher to educate the industry and motivate change in practice, or a change in the PAIL standard itself.

A framework where irrigation is integrated with other field operations

The ISO11783 data format (International Organization for Standardization, 2015) is commonly used to represent planned tasks (i.e, work orders) and actual tasks (i.e., work records) for the field operations of planting, tillage, crop protection, crop nutrition and harvest. It is not commonly used in irrigation, however, and examination of the format documentation shows some good reasons for it: ISO11783 cannot easily accommodate the radial geometries inherent in center-pivot systems, for example. In addition, the ISO11783 format is complex to understand, and pervaded by tradeoffs (such as avoiding the representation of floating-point arithmetic) that were appropriate at the time the ISO11783 standard was conceived, but are not necessarily useful today. The PAIL standard, on the other hand, is highly aligned with the new ADAPT object model (AgGateway 2016) which retains backward compatibility with ISO (for the benefit of the other field operations mentioned) but provides richer, business-process-oriented semantics where irrigation can coexist with the other operations as parts of a grower’s business process. In the current context where growers must comply with complex crosscutting regulatory requirements as an everyday cost of doing business (e.g., reporting on application of crop nutrition products delivered through irrigation), this integration is likely to be very advantageous and time-saving for the grower.

Conclusions

PAIL is a data exchange standard that creates a “common language” for irrigation technology. This common language addresses a critical issue in the irrigation industry: tools that could improve water management are not used because of the burden associated with integrating them into the management process. The standard will promote adoption of improved management practices by making technology easier to integrate into the farm enterprise.

The PAIL team developed a set of Use Cases, User Stories, and BPMN diagrams that describe the irrigation management process. The processes are derived from a grower’s perspective and represent management processes as they are now rather than an idealized representation of what they should be. Based on these process models, the team designed a robust data model that incorporates all of the relevant data flows and messages. The data model is rendered as an XML Schema and, when the standard is published, this schema will be available publicly. Two field trails serve to validate the efficacy of and demonstrate the utility of the PAIL standard. These trails will also serve as the foundation for documentation and training materials.

The PAIL standard will be submitted to ASABE for balloting in Q3/Q4 of 2016. Once the ASABE standard is accepted, PAIL will also become an ISO standard. The development process is ongoing. The PAIL team is currently working on additional sections that cover drip irrigation, pumping systems, and testing. Any person interested in participating on the PAIL team should contact member.services@aggateway.com.

References

AgGateway. (2015). "The Spade Project." *The Spade Project*, PDF, , <http://s3.amazonaws.com/aggateway_public/AgGatewayWeb/About%20Us/CommunicationsKit/AgGatewaySPADE3_11415.pdf> (Jun. 13, 2016).

AgGateway. (2016). "The ADAPT Toolkit: Implementing Interoperability in Precision Agriculture." *The ADAPT Toolkit: Implementing Interoperability in Precision Agriculture*, PDF, , <http://s3.amazonaws.com/aggateway_public/AgGatewayWeb/About%20Us/AgGateway_ADAPT_Toolkit_5616.pdf> (Jun. 13, 2016).

Alexandratos, N., and Bruinsma, J. (2012). *World agriculture towards 2030/2050: the 2012 revision*. ESA Working paper, FAO.

Baulcombe, D. (2010). "Reaping benefits of crop research." *Science*, 327(5967), 761–761.

Colorado State University. (n.d.). "Agricultural Water Conservation Clearinghouse." <http://www.agwaterconservation.colostate.edu/ToolsWeather.aspx> (Jun. 6, 2016).

Fallside, D. C., and Walmsley, P. (2004). "XML schema part 0: primer second edition." *W3C recommendation*, 16.

GS1. (2014). "Global Location Number (GLN)." *Global Location Number (GLN) | GS1*, Text, , <http://www.gs1.org/gln> (Jun. 13, 2016).

Hillyer, C., and Robinson, P. (2010). "Envisioning The Next Generation Of Irrigation Schedulers." *5th National Decennial Irrigation Conference Proceedings*, ASABE, St. Joseph, Michigan, Phoenix, Arizona.

International Organization for Standardization. (2005). *ISO/IEC 19501:2005 Information technology -- Open Distributed Processing -- Unified Modeling Language (UML) Version 1.4.2*. International Organization for Standardization, Geneva, Switzerland.

International Organization for Standardization. (2011). *ISO 19156:2011 Geographic information -- Observations and measurements*. International Organization for Standardization, Geneva, Switzerland.

International Organization for Standardization. (2015). *ISO 11783-10:2015 Tractors and machinery for agriculture and forestry -- Serial control and communications data network -- Part 10: Task controller and management information system data interchange*. International Organization for Standardization, Geneva, Switzerland.

Jacobson, I. (1992). *Object-oriented software engineering: a use case driven approach*. ACM Press ; Addison-Wesley Pub, [New York] : Wokingham, Eng. ; Reading, Mass.

Leach, P. J., Mealling, M., and Salz, R. (2005). "RFC 4122 - A Universally Unique IDentifier (UUID) URN Namespace." *IETF Tools*, <https://tools.ietf.org/html/rfc4122> (Jun. 13, 2016).

Raymond, E. S. (2001). *The cathedral and the bazaar: musings on Linux and Open Source by an accidental revolutionary*. O'Reilly, Beijing ; Cambridge, Mass.

von Rosing, M., White, S., Cummins, F., and de Man, H. (2015). "Business Process Model and Notation—BPMN." *The Complete Business Process Handbook*, Elsevier, 429–453.

Schaible, G., and Aillery, M. (2012). "Water conservation in irrigated agriculture: trends and challenges in the face of emerging demands." *USDA-ERS Economic Information Bulletin*, (99).

Smith, R., Baillie, J., McCarthy, A., Raine, S., and Baillie, C. (2010). *Review of precision irrigation technologies and their application*. A Report for National Program for Sustainable Irrigation, University of Southern Queensland, National Centre for Engineering in Agriculture.

Taylor, K. (2009). "Final Report of the 'Scheduling irrigation for commercial agricultural growers within the El Dorado Irrigation District using permanently placed soil moisture sensors' Project."

TruePoint Solutions. (2008). "TrueISM." <http://www.truepointsolutions.com/trueism.htm> (May. 28, 2010).

USDA. (2012). *Farm And Ranch Irrigation Survey (2013)*. National Agricultural Statistics Service, Washington, D.C.

W3C/IETF. (2001). "URIs, URLs, and URNs: Clarifications and Recommendations 1.0." *World Wide Web Consortium (W3C)*, <https://www.w3.org/TR/uri-clarification/> (Jun. 13, 2016).

Wang, D., and Cai, X. (2009). "Irrigation Scheduling---Role of Weather Forecasting and Farmers' Behavior." *Journal of Water Resources Planning and Management*, 135(5), 364–372.