AgGateway Traceability API – The Foundation to Track Commingled Raw Agricultural Commodities

Authors

Nieman, Scott; Digital Ag Architect - Truterra / Land O'Lakes, USA

Tevis, Joe; Agriculture Consultant - Vis Consulting, USA

Craker, Ben; Portfolio Manager - AgGateway, USA

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Abstract.

There is increasing demand for food traceability, ranging from consumers wanting to know where their food comes from, to manufacturers of agricultural inputs wanting to know the effectiveness of their products as used by farmers. Existing traceability requirements focus on the supply chain of goods packaged from their origin to retail grocery stores, with regulations provided by the Food Safety Modernization Act (FSMA) from the US Food and Drug Administration which suggests use of Critical Tracking Events and Key Data Elements to manage this challenge. Excluded from the list of foods, the Food Traceability List, for which additional information is required by FSMA, are commingled Raw Agricultural Commodities (RACs) such as grains and milk, which were viewed as a daunting effort to manage. AgGateway members studied this challenge since FSMA's introduction, and introduced new types of Critical Tracking Events including the Transfer Event, when used with the Traceable Resource Unit, have become a foundation model to confidently manage RACs and help the 'last mile of integration' from the supply chain to digitized field operations. This model is only limited by existing farm equipment design, ability to exchange the device configurations, and what can be accurately logged on a machine. The use of emerging AI-based grain and fluid flow models, and farm and field practice changes are supported by this model to improve the confidence in tracking RACs. Taking it a step further, the foundational model leveraged new and existing standards-based 'core components' assembled in a NIST developed software tool called 'connectCenter'. Utilizing connectCenter a general Traceability API was created as an OpenAPI specification describing endpoints to manage these resources, allowing software developers to generate code in the programming language of their choice and embed these capabilities into OEM platforms, farm management information systems, and retailer ERPs. This OpenAPI specification of the core concepts of the CTE, KDE, TRU and Containers are intended to simplify software implementation, thus accelerating adoption and making it easier for the farmer to meet the increasing traceability demands without impact to their farm operations.

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Keywords.
Traceability, KDE, CTE, TRU, OpenAPI, DDOP, Device Configuration, Container

Value Proposition

There has been a long-standing and increasing need for traceability within the Agriculture / AgriFood industry. Key business value includes:

- Consumers are wondering where their food comes from (GMO, Organic) and restaurants are seeing competitive advantages of locally sourced food;
- AgriFood manufacturers and processors are paying more for premium and Climate-Smart commodities with higher nutritional value and those shipped directly from the farm to their processing plants;
- Reduce cost of recalls through search of semantically linked data meeting regulatory agencies traceability requirements, including issues related to seed lot germination issues, and raw agricultural commodity quality;
- Document in-field effectiveness of crop inputs allowing manufacturers to understand if changes are needed or if production of a non-effective product should cease;
- Improve confidence that commingled raw agricultural commodities can be tracked and traced with a high degree of confidence.

Some of the key value statements from a technical perspective include:

- Leverage established terms such as Critical Tracking Events and Key Data Elements that are familiar to others that have been researching traceability;
- Introduce the Transfer Event as a new Critical Tracking Event, as a 'first class citizen' with equivalent if not greater importance than Transport Event;
- Formalize the definition of the Traceable Resource Unit rooted in ontological work as an OpenAPI, providing future foundational capability to bridge between modern data exchange technology into a Knowledge Graph supporting artificial intelligence efforts;
- Enable faster AGILE delivery of software implementations using defined OpenAPI specifications and modern code generation techniques including NSWag and Swagger CodeGen;
- Illustrate the importance of AgGateway's In-Field Product Id OpenAPI standard to improve data quality of field operations datasets, by allowing import of retailer shipped item instances into the tractor display as product lists to aid crop identification and capture of seed lot identifiers.

The Traceability API is the most recent AgGateway standard developed in connectCenter. Version 1 of the Traceability API is specific to seed planting operations and planter box (hopper) fill operations. We believe it can also handle crop nutrition and crop protection applications with tank fill operations. It is designed to also handle the 'disconnected' off-line reality in the field, while allowing synchronization to cloud platforms once connected. We recognize the limitations of equipment and technology in use today and offer recommended 'opportunities' for future work. Even as of this writing, the API is flexible to the level of granularity needed or desired by the operator / farmer, or the capabilities of the implement used by the farmer.

Introduction of the Transfer Event in the CART Project

The Commodity Automation for Rail and Truck (CART) project was formed ten (10) years ago as a collaboration between the AgGateway Precision Ag Council and the Grain and Feed Council. The goals were heavily driven by the Food Safety Modernization Act (FSMA) from the US Food and Drug Administration and general needs for commodity origin raised by grain elevators, processors and animal feed manufacturers. At the time, the scope of FSMA was not clear whether grain was to be included. The commingled nature of grain handling, and the increased size of grain bins to meet the needs of the ethanol and other mass processors made tracking very daunting. Many elevators (still) operate without integrated process control systems for detailed bin and conveyance management including load-out bin blending. AgGateway met regularly with the American Feed Industry Association, which represented many elevators and feed manufacturers and provided lobbying services when legislative challenges were presented.

AgGateway CART teams expanded on prior Precision Ag work, the team analyzed existing SPADE planting and harvest business process models represented in the Business Process Modeling Notation (BPMN). Additional models expanded this collection, capturing the shipment process from on-farm storage to grain elevators, from grain elevators to processors, as well as Direct Ship from the farm to processors. Numerous observations were made that indicated the need for process improvements through automation and integration. The design of bins and controls within bins were areas of concern, as well as the methods of conveyance to and from these bins and potential damage due to equipment.

An additional observation was that grain handling included many transfers from one container to another, which led to concerns on how to model the partially full / remainder problem. The first step was to leverage prior knowledge of Critical Tracking Events in other traceability efforts particularly in packaged and discrete products in shipping containers. But the commingled problem was 'different' due to commingling in intermediate storage containers, from planter bins, to combines, blending from multiple containers into one target container and even the arable field where seed was planted and a commodity was harvested.

We modeled the 'container' as an abstract object, where a field could also be a container. Planting operations include transfers from a tender's bulk box or bags to a planter seed bin, from the bins into the field. And during harvest from the field to combine, combine to grain cart or direct to semi-trailer, and cart to on-farm storage. This was NOT a transport event in CTE terms. It was a beast of its own that involved an indeterminate quantity (hard to quantify) of seed or commodity that was in a container at one point in time, transferred to another container using a device at a specific rate and method over a time period, and either all or some of the item instance was transferred from the source container to the target container.

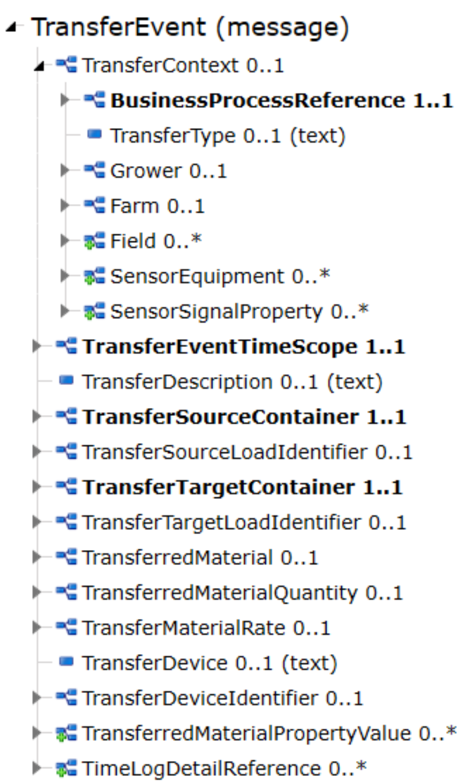

Figure 1- AgXML v5.0 Draft Transfer Event.

We created a large spreadsheet that served as a cross-reference of data elements (rows) to the process areas (columns), and indicated whether data elements were even available within the context of these processes, if they were generated by the process steps, and if so, did they need to be carried forward to subsequent processes where those tasks within the process required these data elements (could not operate without the data).

An XML Schema definition was prototyped to capture the data elements within the spreadsheet. Unlike today's Traceability API schema objects, it captured the notion of transferring an item instance from a source container to a target container. The Device used to transfer was also defined as well as the parties involved with the operation. The prototype was added to the AgXML base and a beta schema v5.0 (Figure 1) was issued and available in the AgGateway Click tool. We do NOT encourage its use, but it was certainly referenced while crafting the Traceability API.

Then began a larger effort for a series of proof-of-concepts using Internet of Things (IoT) approaches. We knew that for large agricultural equipment manufacturers to implement these capabilities would require a series of convincing demonstrations. We conducted Bluetooth experiments using BLE beacons, mobile applications and

AndroidThings on Raspberry Pi computers as a 'Smart Edge Device'. We learned very quickly during these PoCs that there were a lot of ‘false positive’ detections of these beacons. The business rules needed to filter out this noise were a bit daunting for a set of volunteers in a standard setting. For example, when multiple beacons in a vicinity (multiple bins), proximity calculations using the Proximity API were needed to identify the ‘beacon of interest’. More work was needed to learn how to rapidly reprogram beacons with metadata about the container, including an asset UUID, broadcast name, local id, and a given container’s capacities. We engaged with experts from Google to learn more about how this could be done, only to learn Google was dropping the AndroidThings platform. We envisioned an array of solar powered smart edge devices mounted on tenders and planters to identify containers and call tractor display APIs over Wi-fi, or fuse data later on platforms. We had to classify it as an ‘opportunity for innovation' for the agriculture industry.

Commingling of Commodities

We have great curiosity in seed flow in planter bins and tenders, and grain flow within on-farm and elevator storage bins to understand the impact to the Traceable Resource Unit. This is core to the commingling concern and ultimately why RACs were excluded from the FDA Food List, which unfortunately demotivated the industry.

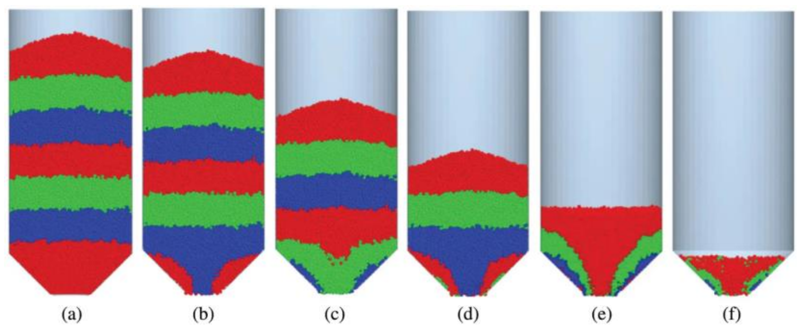

Figure 2 – grain flow modeling from funnel shaped bins.

Bin designs are constantly improving to minimize shouldering effects and remaining quantities. Older bins and silos do not have the funnel shaped design like modern silos, experiencing the age-old 'shouldering effect' of grain, where grain would be held up at the edges of the bin. This meant, without regular maintenance to clear out the older grains, there was a high probability that the volume of older grain would be more susceptible to mold / toxins. Eventually, when the silo emptied, these older grains would make it in the conveyance system and into a shipment. To add to the problem, massive silos have been built to handle the increased demand for shipments to biofuel and ethanol processors. Management of organic and premium commodities are increasingly moving to direct ship from farms to processors to avoid these complications, or smaller bins again for improved segregation.

Mathematical flow models (Sun, 2021) are needed to advance and integrate into process control systems. Elevators will need to modernize, and in some cases, *actually implement process control systems* at their facilities to manage transfers from dump pit to storage, to load out bins. Tenders and planter bins need similar capabilities as newer combines which can shut off the floor auger then clean out the unload auger when the unload auger is “shut off”.

Critical Tracking Event (CTE) and Key Data Elements (KDEs) Origins

Critical Tracking Event (CTE) and associated Key Data Elements are notions adapted from the Institute of Food Technologists (IFT) and detailed in a dissertation by Benjamin David Miller (Miller, 2014). Miller describes the approach from which these notions emerge as a *logistics perspective* that “…simplifies the supply chain into a series of events through which food containing units pass.” AgGateway’s traceability work defines CTE as, “An occurrence where information is captured representing history relevant to a product’s genealogy. This includes occurrences to product or material, as well as occurrences involving equipment with which product or material came into contact.” Key Data Elements identify answers to what, who, when, and were associated with the CTE. The CTE approach provides a consistent way to both specify data requirements and capture data across a supply chain relevant to traceability. CTEs occur both internally to a stakeholder and at boundaries between them (external).

In September 2023, IFT and the Council for Agricultural Science and Technology (CAST), jointly released an issue paper aimed to address the U.S. Food and Drug Administration's end-to-end traceability mandate for food and agricultural products (CAST 2023). It focused on discrete package product tracking in the Supply Chain, tying external events during shipping and receiving, to internal tracking events during food manufacturing processes including batching and packaging. In a brief mention, it was emphasized that commingled raw agricultural commodities (RAC) are out of scope for the food list. Therefore, no mandate exists in the United States at this time, so there is limited motivation other than higher value and commodity pricing of premium grain, especially those commodities grown with sustainability practices, i.e., more soil nutrients.

We confidently assert that grain traceability, for a significant percentage of the shipped commingled RACs, is possible with a high degree of accuracy if the software techniques outlined in this paper to capture Transfer Event CTEs and Traceable Resource Units are used. Applying these concepts, researchers will ultimately be able to assign a statistical 'confidence level' to this degree of accuracy using mathematical, data-driven techniques.

This foundational work is also a call for action for industry commitments from the OEM equipment manufacturers, retrofit vendors, and the entire supply chain. Starting from crop input manufacturers implementing detailed product labeling using Cristal guidelines to ag retailers for scanning and shipping controls.

Origin of Traceable Resource Unit (TRU)

Terms for the units tracked differ within the supply chain, but CTEs apply anywhere, there was a need for a common term for the role of the things being tracked in any CTE across the supply chain. The University of Toronto had coined the term Traceable Resource Unit (TRU) for the "resource representation that must be traceable" in their work on the TOVE Traceability Ontology (Kim, 1995). This term has been adopted by the NIST traceability model and the AgGateway traceability efforts. The definition adopted by AgGateway for the TRU notion is, "A collection of material, discrete product(s), or packaged product(s) treated as a unit for some period for tracking." This notion is key to supply chain traceability, and the notion and term have been independently adopted in other communities, as seen in an FAO circular regarding seafood traceability systems (Borit, 2016).

Reference to Ontology Research at KSU and TSU

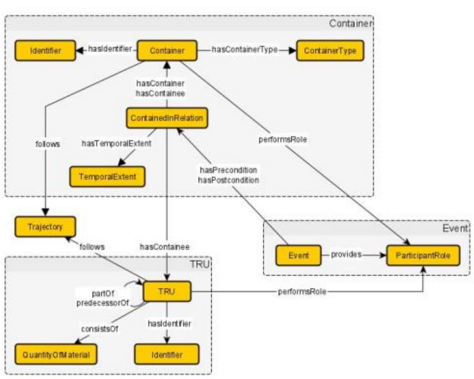

Figure 3 – Critical Tracking Event Diagram.

Formal definition of the concepts of the Critical Tracking Event and the Traceable Resource Unit were needed, therefore research on the topic was conducted by leading ontology experts Pascal Hitzler and Cogan Shimizu from Kansas State University and Farhad Ameri from Texas State University (now Arizona State University). Having these discussions with notable authors and leveraging formal modeling techniques that form the backbone of the Semantic Web yielded great results.

We shifted our focus away from a container-centric view to a quantity-of-material centric view, where the container only has a role in the process.

Not only did we model the Transfer Event, but also Observation Event for qualities of the material, Maintenance Event for the care of the containers and measurement instruments and a new and significant Identification Event. Just to identify something was an event of its own, involving auto-id techniques when available such as bar-codes, beacons, or RFID tags. We needed to identify all the containers (fields, bags, bulk boxes, planter boxes/bins, combine bins, carts, etc.) and we needed to identify seed, crop inputs, and the final commodity.

A snapshot of this body of work funded by NIST was presented to AgGateway members during the 2020 Annual Conference in virtual sessions. NIST has continued its involvement in traceability work at AgGateway and use cases from these efforts have driven enhancements to the traceability ontology. Results of this work are documented in (Ameri 2022).

A modern OpenAPI specification useable by Developers

Our next step was to take the ontology work and transform it into a developer friendly OpenAPI specification yaml (yet another markup language) file. We had already been using the open-source tool called connectCenter (formerly SCORE) for other efforts like Product Catalog, In-Field Product Id, and Scale Ticket, so it only made sense to continue to leverage it.

The fundamental motivation of specifying an OpenAPI is that the programming frameworks have evolved to the point where RESTful Web APIs are the norm. The newly trained development workforce wants to use these tools to deliver integration solutions. Embracing this technology is valuable at a time when the agricultural industry must build up its workforce and attract talent to meet the demands of feeding the world in a sustainable manner. These capabilities enable faster delivery of solutions to enable data collection. Farm Management Information Systems and ERP systems need modern and appealing integration techniques to provide that stickiness to their customer base. Digital Ag platforms have been moving to the ‘microservices' architecture, where 'models', 'views' and 'controllers' (MVC pattern) is part of the daily conversation amongst developers. The 'Data Transfer Object' (DTO) is where the Traceability API fits in the MVC paradigm, where the DTO represents the 'top-down' domain model in Domain-Driven Architectures that often requires orchestration across multiple entities in the database model.

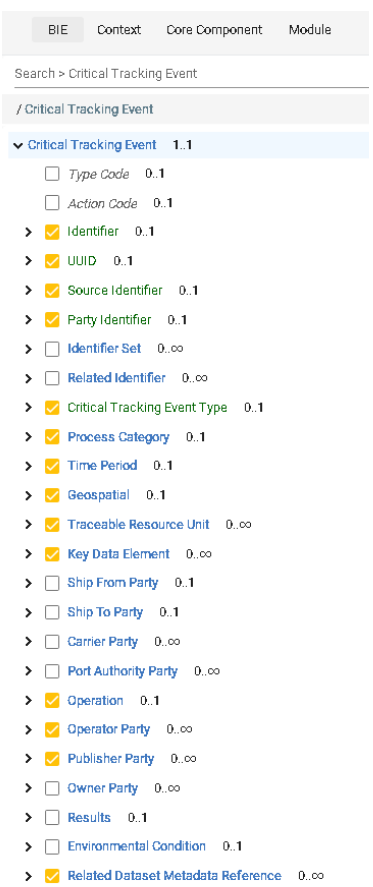

Figure 4 - Critical Tracking Event BIE in connectCenter

While programmers are able to generate APIs, they are also able to rapidly generate poorly named and inconsistent APIs. To date, most vendor driven API definitions are very arcane with inconsistent naming across endpoints, terms that are hard to understand, and incomplete capabilities. Without a baseline of a standard set of core components, interoperability tends to lead to more point-to-point integrations. AgGateway has focused its efforts on standards-based interoperability, where agricultural workers define standards in a common language used within the agriculture industry or cross-industry especially in the case of supply chain.

connectCenter hosts a library of core components that serve as the semantic building blocks to assemble and specify data exchange messages at varying degrees of size and granularity. Some of these components are pre-assembled documents such as Purchase Order, Production Orders, Invoices, (Product) Catalog, etc. When placed into a business context, the reusable components can be profiled as ‘business information entities’ (BIE) by visually picking and choosing properties needed in that business context, adding context specific definitions of property, example data, and ensuring the property or component cardinality meets the requirements of the specific context. Most often these properties are identifiers, names, descriptions, quantities, classification codes, etc.

The Traceability API was assembled from scratch. For the CTE component, Identification Details was selected as the base inheritable type, and then existing components from the library were added to it. For the TRU, the Item Instance Base was selected, which is the same base component of the standard Shipped Item Instance used in the In-field Product ID API. The most important point is that most components have extra properties that are not needed in our business (bounded) context, so when the Business Information Entity was profiled we simply would not select those properties. Profiling the BIE included adding a meaningful description of the property, ensuring that property or objects had the proper cardinality and adding example data. The tool allowed rapid prototyping, and once expressed as a BIE, to quickly look at the resulting sample data in Swagger Editor.

An OpenAPI specification typically requires many of these messages respond in a RESTful manner, so many BIEs are needed. These can then be further assembled into the OpenAPI document, specifying the RESTful HTTP verbs, resource paths, operation ids, etc. These verbs perform behavioral capabilities such as creating new resource instances (POST verb), updating resources (PATCH), querying (GET) resources, replacing resources (PUT) or removing (DELETE) of resources from a database. The tool offers some default logic based on programming patterns and practices that developers expect, in order to meet the desired experience in Integrated Development Environments such as Visual Studio, Eclipse, etc. The expression from these definitions to the YAML file is also based on patterns, with mappings for the path, schema objects, etc., as defined by the OpenAPI consortium. This YAML is viewable in Swagger Editor. AgGateway members worked closely with NIST to refine and enable the merge of multiple BIEs into a single OpenAPI specification out of the connectCenter tool allowing more complete YAML and better code generation.

Utilities like Swagger CodeGen and NSwag for .NET generated the ‘Model’ of the formats (used by both client and server) as well as ‘Controllers’ used in the Model-View-Controller design pattern.

The below snippet of the generated Controller for the GET /traceability/V1/traceable-resource-unit-list endpoint illustrates the mapping:

```
[HttpGet]

[Route("/traceability/V1/traceable-resource-unit-list")]

[ValidateModelState]

[SwaggerOperation("QueryTraceableResourceUnitList")]

[SwaggerResponse(statusCode:200,type:typeof(TraceableResourceUnitList,
description: "")]
```

These code generation capabilities are what developers need to speed up their deliveries and meet the ever-expanding demands of agriculture. This includes faster implementation in Farm Management Information Systems, retailer ERP systems, feed manufacturing process control systems, farm equipment OEM platforms, retrofit displays, and IoT smart edge sensor implementations.

Further enhancements for management of mapping specifications within connectCenter are anticipated with this collaboration, allowing AgGateway members to eliminate spreadsheets. The ultimate goal is to import various proprietary business application interfaces (DB tables, REST), create the mapping leveraging AI-assisted schemes, then export a mapping interchange language format that enables further code generation to implement ‘mappers’ and 'handlers' from one format to another. Also code generation from the API schema object to a set of database table definitions using representations common in Hibernate, EclipseLink, Entity Framework Core, and other Object-Relational Modeling tools. This would be intended for on-prem instances of connectCenter.

Capabilities of the Traceability API

The first release of the Traceability API focuses on capabilities to support the "as-planted" business process, starting with the warehouse pick and transport, seed fill (tender), and seed planting operations. Supporting operations are important to cover as without their inclusion, too many questions are raised such as where specific data originates.

The version one (V1) release coupled with complimentary standards, provides the industry a formal data representation of what has been planted (crop, variety, lot, seed treatment), where the crop has been planted, when planting occurred, who planted it or shipped it, and how the crop was planted. The API captures the critical tracking events related to the quantities of planted seed across both geospatial and temporal dimensions represented as traceable resource units.

Our evaluation suggests the Traceability API will also handle crop protection application processes as well, but additional modeling should be considered for modeling tank mixes, another supporting operation.

As a quick primer of RESTful API techniques, it's important to understand that the URL is the fundamental means to access the 'resource' we are interested in via the RESTful verbs described earlier. Most people are familiar with the Internet browser's use of URL to access web pages, but the RESTful techniques require more 'rigor' aka specification for integration purposes.

In the case of software development, it is not necessary to specify every single Create-Read-Update-Delete (CRUD) combination with these resources. That is the mistake of most other standards organizations, they will specify the 'standard' but its usage is not realistic. In creating the API definition, we made that mistake, stopped and corrected our work. We took a step back to reanalyze its usage by creating a UML sequence diagram that illustrates the business process and capabilities and features needed for the as-planted business process articulated in Table 1.

The two supporting operations that are common prerequisites to the fill and planting operations are the field selection operation and seed allocation operation. There are a number of key features and nuances that are important and were the point of considerable debate, ultimate agreement to the best approach was based on considering the variety of capabilities across equipment, and cost to the farmer (ability to afford these capabilities).

The field selection operation, while it seems obvious, involves determining which field will be planted on a given day. While there may be many commercial systems that allow the retrieval of a field, the Traceability API GET /field-list endpoint provides a simple facade API capability to retrieve a list of fields for a farm location the farmer has under their management. This basic listing uses simple, yet standards-based components that describe the field by name, description, local field identifiers and a cross-reference of searchable related identifiers managed in other systems. Field metadata can be queried by text matching, known identifiers managed by a farmer's partners, farm name, location identifier such as GLN, etc. The related identifiers cross-reference approach provides a robust means to store and manage any identifier from other agencies such as USDA FSA farm, tract, and field identifiers. The GET /field-boundary itself provides the additional detail of the geospatial boundary in any format (GeoJSON, WKT, Shapely, shp, etc.) with detailed related identifiers attached. Traceability API leverages the connectSpec 'Related Identifier' component as an array, so identifiers from multiple systems and partner's instance of the same field can be cross-referenced, since a 'standard field identifier' is nearly impossible to agree upon. Cross-referencing these identifiers with this scheme {id, sourceId, partyId} reduces field duplication. Additionally, operational boundaries can be geospatially intersected to determine exact field matches or partial field matches accounting for subtle differences in area calculated from a specific planting operation.

It is essential for the success of the Traceability API that referential integrity be maintained throughout the process. Simply put, the same identifier assigned to any entity must be used consistently in all transactions and CTE and TRU creations. This includes all containers including fields, crop input products and parties. The preference is that all identifiers be globally unique, but the functional minimum requirement is that they be consistent. In some cases, this may require

Table 1 – Capabilities for the as-planted business process.

RESTful resource	Capabilities provided
operator-party	Identification of the operator performing the operation
operation	Identification and classification of the operations performed on the farm. The 'as-planted' process context has the following operations: Warehouse Pick and Transport, Seed Fill / Tender, and Seed Plant
fields	Retrieval of Fields to select from. Selection of the specific field and its geometry where the process operations will be performed. This selected field becomes a target container during the actual planting operation.
device-resources	Identification of the devices that will be used during the as-planted process and operations. The device resource can be a planter, fork-lift, auger, tender, etc. Containers on a device can be determined through introspection. Key devices have a configuration that specifies its technical features important for precision agriculture.
containers	Identification and selection of the containers that will hold the seed during the as-planted operations. These containers include bags, totes, bulk boxes, planter boxes/ bins, and even the field itself. Some containers must be identified by interpreting the device-resources, specific to a planter or tender configuration
container-state	Identification of the status of the container (empty, partially full, full) at a specific point in time. The particular nuance of when the fill operation will take place, as in the real-world, is often based on what is convenient for the operator, and therefore there may be instances where remaining quantities of seed are still in the planter box when it is convenient to refill. That means commingling will occur, but the concern if the tender has a single lot of seed is minimal.
traceable-resource-units	Identification of the source and target traceability resource units that are involved during the transfer of seed between containers. Supports a Product-centric view, specifically the capturing of attributes that relate to a specific instance of the product. Load in ISO and ADAPT are the closest thing to the TRU, however, Load is harvest specific whereas TRU handles all use cases. Ability to create new TRUs, and note when they are active or completed, including their time period and geospatial relationship. Ability to denote the transport of a single TRU, for example from one point to another.
critical-tracking-events	Ability to identify key CTEs for the as-planted process, including Transport Events (Pick from the warehouse, and transport to the field) and Transfer Events of TRUs for Pick, Fill, and Planting operations. Ability to link CTEs based on the relationships of the TRU across CTEs, required generation of identifiers such as a GUID, sharing that across the as-planted process operations. For example, a Target TRU (by value) created in one CTE may become a Source TRU (by reference) in another successor TRU i.e., in another step in the process. Ability to specify Key Data Element to append the CTE to further help with data linking and query. KDEs are most often identifiers of different business objects such as a ShipmentID, Lot or Batch Identifier, Cart ID, Semi-Trailer USDOT identifiers, etc.

a mapping between identifiers for the same entity already is use. Such mappings must also be consistent. Visibility of all identifiers by all business partners may at times present some privacy concerns. These can be minimized by limiting identifier exposure of any single entity to only those partners that interact with that entity. For example, a semi delivering a load of grain to an elevator the trucking company, grower and elevator must use the same identifier for the semi. However, the elevator does not need visibility to the identifier for the seed tender or planter used in the planting operation.

The Traceability API is critically dependent on the In-Field Product Identification API, which allows the capabilities to load shipment details (delivery documents) into the tractor display. These implementations are currently based on ADAPT to transform the "Shipped Item Instance" (same base component as the TRU) to ISOXML and ADAPT ADM representations which have been successfully loaded into OEM platform systems. The current cab display product list is only a product reference list, for crop and variety at best. We realized this must become a product instance list to be successful, which only makes sense, as the operator is always dealing with real instances of seed with a varying size, density, lot information, seed treatment, and germination success. Cab displays must evolve to display additional instance-related information such as lot identifiers and their shipment identifiers for more precise selection, as the same seed lot could occur in more than one shipment. These identifiers are critical to link field operations to the supply chain. In-Field Product ID proposed the concatenation of product and lot id as an interim solution.

We also determined the Traceability API is fully capable of representing picking seed from inventory in the shed/ warehouse, the Transport Event of inventory to the field, and the Transfer Event(s) from the shipping containers to a tender or direct to planter bins (if one bin per row). Sometimes the Transfer Event occurs in the field, and sometimes in the shed or the yard near the shed. This is not represented in the UML sequence diagram but follows similar logic as the fill operation. The shipping container itself is a pre-defined TRU in this process, and could be a set of seed bags, a tote, or a bulk box ready to be set on the tender.

There was much debate within the work group centered around the Fill operation, which is defined around the work needed when the operator starts the fill or a refill when the bins are (near) empty and when they begin rolling (again). The fundamental question was whether there are multiple CTEs for each fill operation where a Transfer Event CTE has only one source and one target Traceable Resource Unit, or whether there is one CTE per fill operation, where there are multiple target TRUs and potential multiple source TRUs. The Critical Tracking Event in the Traceability API has the flexibility to allow for either situation, the generated payload really depends on what is *practical* for the operator and allowed based on the device configuration (device-resource) information. This is covered later in the paper where we discuss the level of granularity, but fundamentally we know that the logging of the CAN messages to stop and start the planter are important boundaries to the Fill operation, i.e., the 'scope of the CTE'.

It is this level of granularity, linking geospatial detail to the capture of the TRUs for the planting process that builds the industry confidence in the commingled grain use case. As that geospatial intersection of the planting operations that has had careful TRU logging will provide higher confidence especially in direct ship from field to processor scenarios.

Level of granularity dependent on the planter configuration

Much of the work to-date has been based on the ISO 11783 standard for agriculture electronics. Known in the industry as ISOBUS, it provides a standardized method for sensors, controllers, and other electronic components that comprise a tractor-implement combination to “talk” to each other. The Device Description Object Pool (DDOP) defines a framework for equipment manufacturers to provide a digital description of the physical machine instance. The DDOP includes dimensions and offsets of a device relative to a GNSS receiver location, the number of metering points that often correlate to product bins, as well as the hitch point and type between the tractor and implement(s). This information is integral in translating the time series data recorded by a machine to geo-spatial representations of what the machine did where. While not all machines follow the ISO 11783 standard the same concepts exist within proprietary data formats used by some manufacturers to document field operations.

How a machine is physically configured as well as how the manufacturer defines the digital representation of the machine in the DDOP (or proprietary equivalent) can have a large impact on the granularity of the geo-spatial data generated during a planting operation. Often there are differences in the level of granularity a machine is physically capable of and what it can do electronically. For example, a 24-row planter with electric drives on individual row unit meters can physically control the speed of the drive and thus seeding rate at the individual row level, making each row a section. However, due to limitations in electronics in the terminal or elsewhere in the system, multiple rows may be grouped together, possibly in six groups or sections comprising four row units each. For planters with mechanical or hydraulic drives there is generally less granularity possible since one drive controls multiple row units simultaneously, this can result in a 24-row planter that has two 12-row sections, essentially a right and left side that can be controlled separately, while there are likely still sensors on each row monitoring seeding rate.

Additionally, the configuration of the product bins on the planter also plays a role in the level of granularity of geospatial product placement information. For planters with individual seed boxes on each row unit, this provides the capability to link a bin to a meter and thus where the seed was placed in the field. Planters with central fill hoppers consist of a few larger tanks that deliver seed to mini-hoppers on each row unit where metering takes place. For the 24-row planter configuration it is common to have two tanks, one for the right side and one for the left. These planters are much more suited for handling bulk seed, but bags can also be used. This makes it a little more difficult to understand what seed went to which row unit since it is comingled in the planter bins.

While the DDOP helps identify the control points on the BUS of the machine, it does not provide identifiers or other information about the containers the metering devices are attached to. This is one area that could be improved in either the ISOBUS standard or proprietary implementations. Accurately tracking product through the machine can be difficult without clear identification of the bins involved. Without the identification of these containers CTE and TRU management is difficult since assumptions have to be made about quantities transferred and where the seed is located on the machine. Even having access to basic information like the capacity of a tank or hopper would be helpful to understand quantities being transferred.

Future AgGateway and Affiliate Work Efforts

AgGateway

Field boundaries are an issue across the agricultural industry for a variety of reasons, as a result AgGateway has established a series of working groups on the topic. The first documented definitions and use cases for the field and field boundary concepts. The next working group is focused on accurately documenting GNSS positioning information and related metadata so a recipient can determine if the boundary is of sufficient accuracy for their purposes. It is expected there will be subsequent working groups working on identification, related data like obstacles and entry/exit points, and other topics as determined by the membership.

As farms continue the trend of increasing in size and sophistication, a need has been identified for generating ship notices from the farm level. Historically farms have not used a real ERP to manage their business. However, with the growing interest in climate smart commodities or other products with premium qualities that are only identified by the data about how they were produced, the definition of an advanced ship notice from a farmer's ERP to an elevator or processor is needed. This would allow the elevator or processor to prepare for delivery of these premium products in the event they need to be handled differently from traditional commodities. The main hesitation has been the lack of systems in use at the farm level to implement the message.

Specific to Traceability API, we plan to expand to more business contexts beyond planting and look at 1) Crop Protection and Crop Nutrition Application processes that require mix / blending tasks, and then 2) circle back to the Harvest process we started in CART. While we anticipate reusing many capabilities for these processes, the BIE profiles will require additional refinement and perhaps features for tank mixes.

The most important part of our work will be a set of **Traceability Implementation Guidelines** with specific suggested rules for the identification of TRUs and CTEs. This is the subject of our next paper.

NIST / OAGi

Leveraging our partnership, AgGateway will continue to provide requirements to add features to connectCenter, currently at V3.3.0. We have completed wireframe UI mockups to specify endpoint details including query and path parameters, HTTP headers for request and responses, handling of HTTP 4xx and 5xx error response bodies, and detailed examples for specific scenarios.

Academia

We see great potential with ingesting Critical Tracking Event JSON payloads into a Knowledge Graph. Much of the prior simulation work at Texas State University has followed Farhad Ameri to Arizona State University (ASU). We envision using Event Driven Architectures to provide data from API calls and ingest instances into their engine and other tools like OntoDB. For example, it is possible to create an Azure Function App that consumes data off the event grid/ message oriented middleware and transform if necessary the API JSON to formats required by the data stores, so SPARQL queries can be written to query the data and provide insights to various peolpe interested in this data and provide predictive analytics and problem solving.

Modeling of seed and grain movement in bins (planter, storage, transport) must continue to evolve to improve accuracy to capture the amount of material moved in and out of a bin. The mathematical models will advance, and machine learning will soon provide more statistical based confidence levels, such that process control systems can be trained, self-learning and optimized. These datasets and processing models will also help inform the design of bins for more efficient flow into and out of a bin.

Retailer engagement

Retailers need to be better armed with information they can provide to farmers about the value of traceability and sustainability farm practices. Retailers that are engaged with sustainability (Carbon, Nitrogen, Soil Health, etc.) programs now have on staff conservation or sustainability agronomists, who are skilled with practices such multi-cropping techniques including cover crops and inter-cropping, nitrogen reduction efforts, and knowing what traits work well together. Awareness and promotion of in-field product identification techniques by these specialized agronomists will help retailers efficiently provide services to record planting cover crops, water quality improvements, and data collection support.

Communication of value to the farmer may not be so 'appealing' as sometimes this advice means less product sold to the farmer. But when a farmer hears from the retailer that they can actually *save money* with reduced fertilizer inputs and reduced work with no-till, that advice helps build the trust in the retailer and establishes longer term relationships.

But the game changer is if the farmer can get a better price for their commodity if it can be classified as a quality premium commodity, yielding a higher financial return on their investment (Karas). Measurement of these qualities will be important in the long run, which are future services and products retailers can provide to the farmer.

OEM engagement

Other than the citied need for tractor display enhancements, e.g. displays should be able to expose secure RESTful APIs for the selection of a planted product from the product list. The interaction with a display from a mobile application and smart edge devices is the future, and direct connection to the tractor display via its SSID is critical. The tractor display would need to be able to generate an API key to share with a connected device for secure communications.

The tractor display integration of connected implements via pairing over Wi-Fi or BLE is desired. This allows load cell and auger information to be passed from a tender or grain cart to the tractor display for better data logging.

Additional retrofit capabilities for older equipment would be valuable for capture of operations such as manure spreading, and cover crop planting on machines that have not traditionally been capable of collecting data.

Field Input Manufacturer engagement

In addition to the focus on control systems, we need manufacturers of seed and crop protection products to focus on product identification capabilities, including barcoding, RFID tags, or other auto-id techniques of crop input products. Most seed manufacturers have been adding tags to bags for years, but this is not consistent. Data Matrix conforming to the latest CRISTAL recommendations (CropLife Intl 2017) with batch (crop protection) and lot (seed) representing instance data is critical at this point.

Opportunities for Innovation for Startups

We are encouraged by much of the startup activity in the area of innovation using robotics for weed control either through spot application or with laser technology. The ability to share that logged data in a consistent and accessible representation that is meaningful for Sustainability programs would be helpful, for appropriate credit.

More focus on affordable technology for smaller producers of organic and specialty commodities is a great opportunity with some funding targeted in this segment. This could be a prime space for retrofitting older farm equipment to capture traceability and field practice information.

For climate-smart commodities, we predict the farmer will need verification of the nutritional value of the commodity if they are to claim they have a shipment destined for a processor with a Life Cycle Assessment (LCA) or value chain intervention requirements. To accomplish the on-farm quality measurements of origin weights and grades as harvest grain is loaded into a semi-trailer, test equipment for the smaller producer is needed, ideally, leveraging affordable GPIO-based near-infrared (NIR) technologies that could be programmed on a Raspberry Pi that emulates a Dickey-John Instalab.

Summary

What we have presented in the paper represents over ten years of research, trial and error, learning, and in-field pilots aiming to address the traceability challenges of commingled commodities. This is only V1 of the API, and we anticipate more refinement beyond the initial focus on Grain. The model can and will be refined and extrapolated to other products and field operations.

We strongly believe this is foundational work and that the key principle of knowing what commodity has been shipped is by first knowing what has been put into the ground. The ability to capture the transfers of product quantities from one container to another container forms the basis of improved accuracy, and advances in the methods of measuring the quantities transferred and quantities remaining in a container will only raise the confidence. That confidence then raises the value of a premium commodity when aligned with sustainable field practices that translate directly to better nutritional measures.

Understanding of the business value of premium commodities, sustainable practices and improved environmental impact should drive the industry engagement required to accomplish these goals. While the authors have at times felt we have been trying to move a mountain, the release of the Traceability API brings this many steps forward that the linked data with allow agricultural systems to learn by applying advanced technologies such as artificial intelligence and knowledge graphs, to understand and predict the impact of multi-cropping (Jones 2017), circular economy use cases, regenerative and other sustainable agronomic recommendations.

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