Understanding the IPC 175X Data Model

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Abstract
More and more political bodies (countries, states, and unions) are enacting legislation designed to protect the environment from the impact of manufacturing. One category of restrictive legislation is called Extended Producer Responsibilities (EPR). The EPR directive with the biggest impact on the electronics industry is the European Union's (EU) Restriction of Hazardous Substances (RoHS) Directive, finalized in 2003. The RoHS directive restricts the importation into the EU of new electrical and electronic equipment containing six hazardous substances including lead. For manufacturers to successfully comply with RoHS and similar EPR legislation, they need the ability to exchange material content information. This information needs to propagate through the supply chain from the raw material suppliers all the way to the final producer. To deal with this problem, the National Institute of Standards and Technology (NIST) developed a data model to address the underlying material declaration. This data model was used in the development of IPC-1751 Generic Requirements for Declaration Process Management and IPC-1752 Materials Declaration Management. While IPC 1752 was created with a focus on EU RoHS, industry is now faced with a multitude of new environmental legislations and regulations. While many are variants of the RoHS legislation, several address entirely new areas of environmental awareness such as energy efficiency. To address this problem, NIST has developed an updated model for IPC 1752 version 2.0. This model has a larger scope and is more modular making it better suited to address regulations beyond RoHS and meet other supplier declaration needs. This paper looks at the data models used in both version of IPC 1752 and highlights the differences for application developers.

Introduction
Countries around the world are creating legislation designed to encourage manufacturing practices that promote human health and environmental protection. Many of these laws are built around a concept called EPR. EPR shifts the responsibility of a product's negative environmental or health impact directly to the producing company. To manage a product's negative impact will require companies to change product designs, alter manufacturing processes, and track tremendous amounts of product and manufacturing data. The automobile industry was the first industry sector affected by these new regulations. The first major regulation of this type was the end of Life for Vehicles (EVL) enacted in 2000 and amended in 2002. It also lists restricted substances. The electronics industry was next to face these restrictions with the EU RoHS Directive [1] being the major regulation effecting electronics manufacturing which went into legislative force in 2006. The RoHS directive restricts imports of new electrical and electronic equipment containing six substances specified in the directive. For manufacturers to successfully comply with RoHS, they needed the ability to exchange product material content. This information must propagate through the supply chain from the raw material suppliers all the way to the final producer. Unfortunately, when the RoHS Directive was developed the only methodology was developed by the automotive industry as a massive data base. Suppliers were required to enter data into the system and there were many problems with managing such a huge system known as the IMDS. There were no data exchange standards that supported the information required and the electronics industry chose not to follow the path of trying to manage a single data base. This left the electronics industry scrambling for ways to comply with the new law. To fill this gap the IPC, working with industry and National Institute of Standards and Technology (NIST), developed the IPC 1752 standard [2] for the exchange of material data. This insured that industry had at least one tool available to use prove compliance with RoHS.

While a data exchange standard was developed to assist industry in complying with RoHS, the electronics industry is now dealing with the fact that RoHS was merely the first of this new type of law. In fact, environmental laws from all over the world are being developed that could potentially impact every stage of electronics manufacturing. The complexity of complying with environmental regulations is further complicated by two factors: the diversity of the electronics industry and the number and complexity of the applicable regulations. From small technical shops to large multi-national conglomerates, the electronics industry is incredibly diverse in terms of both business approaches and data needs. On the regulatory side, the laws and regulations themselves vary quite a bit across the globe as each regulatory body addresses their own environmental concerns. The combination of these two factors has created a very complex situation for industry. It is simply not feasible to create individual solutions (data exchange standards) for each new law and each business situation. What is needed is a different way of dealing with this situation generally rather than on a traditional case-by-case basis.

Thankfully, in the post-RoHS world, the stakeholders in the electronics industry have learned much about complying with the regulations. The sheer complexity of all the reporting requirements meant that traditional *ad hoc* standards development processes would likely fail to produce a viable data exchange standard. From the start, the IPC 1752 development team decided to use a software development approach as the basis for the standard development process, as this approach will lead to a more modular and robust standard. The initial version of the 1752 standard was certainly considered a success based on a survey done of users who downloaded the standard from the IPC website, but there were still numerous opportunities for improvement. Therefore, the team decided to update the standard to version 2.0 and to use the update as an opportunity to refine and improve on the UML based development approach. Beyond improving the development process, the switch to version 2.0 also provided the opportunity to include the additional functionality mentioned earlier, such as support for new environmental legislation, a generalized supplier declaration, and data management systems development. The following part of the paper looks at the elements that the design team wanted to incorporate into the new version of the 1752 standard using the improved software development approach.

Need for Generalized Supplier Declaration

The practice of requesting information from a supplier extends far beyond material declarations. Information requests for material composition data, manufacturing capability, or even social responsibility information are quite common in the electronics industry. Unfortunately, there is no standard reporting or declaration format. Different forms, systems, and methods are used throughout the industry, leading to inefficiencies in the supply chain. Given the nature of a declaration request and response, it is possible to create a generalized supplier declaration that would work in most business situations. As such, the design team decided to take this approach with the 1752 update.

Data Management System background

Having a material data exchange standard, like IPC 1752, is only a part of the solution needed by industry in order to manage environmental compliance data. The second part of the solution is the underlying data management system (DMS) used to store all the collected data. With a well designed DMS, it should be possible to access the stored information and generate customized environmental reports as needed by downstream customers. While developing such a DMS is by no means trivial, there are certain key features that should be included within its design as with any software system.

Specifically, the DMS needs the following fundamental qualities: functionality, robustness, and maintainability. A well designed DMS will provide only the functionality required by the user and no more. Superfluous complexity and unnecessary function would have a negative impact on both the robustness and maintainability of the system. Because the systems must be operational when required by the user, downtime, both scheduled and unscheduled, can have a negative impact on the user. Finally, the system must be able to meet future needs during its expected lifetime (and sometimes far after, as seen during the year 2000 software issues). These systems must be easily maintainable and have the ability to be upgrade d and modified to meet these new unforeseen requirements. One way to achieve these qualities in a DMS is to focus on building systems that are both abstract and modular.

In fact, the qualities of abstraction and modularity match those found in software industry development processes through the use of object oriented design. Therefore, it follows that using software development methodologies can easily lead to both a new data exchange standard and a corresponding underlying DMS. In theory, the new version of 1752 would provide not only a new data exchange standard, but also a blueprint for developing a DMS that would be ideal for storing material declaration data.

IPC 1752 V1.0 Limitations

The first version of IPC 1752 Material Declaration already provides industry with a solid tool to help industry cope with the EU RoHS Directive. However, as industry gained experience with the 1752 standard, several issues were encountered. Many of these issues are features that were beyond the scope of the original standard. However, their absence clearly limited industry acceptance of the standard, so they needed to be added into version 2.0 of the standard. Functionality most commonly requested by users includes the incorporation of multiple part data in one file, support for data authentication, and support for new legislation.

Limited Support For Multiple Part IDs
In IPC 1752 v1.0, a product part family must be described using a single PartID attribute, and all the parts described must have the same weight. This constraint is fine if the part family has a unique identity. However, this limitation presents problems if the part family is composed of parts which each have their own unique ID. While it is possible to associate multiple IDs in version 1, the IDs are presently squeezed into one attribute/field. A better solution is to incorporate support for multiple part IDs from the start.

Only One Sub-level reporting (BOM)
In IPC 1752 v1 (covering v1.0, v1.01, v1.02, and v1.1), individual parts can only be broken down one level into subparts. A subpart can not have another subpart (i.e., no nesting). While this approach can work fine for simple declarations, this flat view of a product makes it difficult to express complex electronic products effectively.

Data Authentication
An important aspect of the first version of the 1752 standard is that it contains legal as well as engineering information. As such, the users of the standard identified that it was necessary to be able to verify the authenticity of the material declaration. (i.e., ensure that it is an actual declaration from the expected stakeholder). One method of providing this authentication is to use some type of digital signature to sign the data. The customer can then verify that the data is from the correct supplier and that the data has not been changed after it has been signed. The original version of the 1752 standard actually provides an implementation of the standard using an active container that provides basic data entry and editing functionality; however, it is not capable of importing or exporting a signature in an XML instance; therefore, the XML files cannot be signed. As the IPC 1752 v2.0 focuses on the XML instance and does not define or provide any data management tools, this functionality needs to be managed within the XML itself.

New Legislation
Because no other major laws or declarations affecting material declaration for the electronics and electrical industry had been finalized when the first version of the IPC 1752 standard was designed, the regulatory information is specific to the EU RoHS and its exemptions. With several new regulations on the horizon, each with new material data requirements, it is not surprising that one of the most requested features was the ability to support these new regulations. Two of the most prominent upcoming regulations are China's "Administrative Measure on the Control of Pollution Caused by Electronic Information Products" [3] (often referred to as China RoHS) and the EU's Registration, Evaluation, Authorization and Restriction of Chemical substances (REACH) [4]. While the new Chinese material regulation has several significant differences from the EU RoHS regulation, in practice this will result in only minimal changes to the supply chain. The impact of REACH on the electronics industry is still unclear. The REACH regulation itself is aimed at the chemical industry, which supplies the electronics manufacturing industry, and not at the electronics industry. Still, REACH does potentially add additional data exchange requirement to the supply chain. REACH covers all substances on their own, in preparations, or in articles (a chemical or collection of chemicals formed into a new shape), and as such chemical usage and safety information need to be exchanged both up and downstream within the supply chain. Not surprisingly, it has been a common request from 1752 users that the material declaration standard information necessary to support REACH be included. In general, REACH is not aimed at regulating articles, which are the typical products that flow through the electronics industry supply chain. Still, REACH will have some impact, such as requiring the communication of material data for Substances of Very High Concern (SVHC) over 1000ppm within the article (not the material). In addition, the supplier must provide this data free of charge and do it within a 45 day period from the request.

Implementation Issues
As discussed, the first version of the 1752 standard ships with a implementation of the standard that includes basic data entry functions. While providing a working tool, this active document also introduced some issues for users. Some reported technical issues including limitations when working on large datasets, no support for XML signatures, and problems with merging documents. None of these technical issues reflect problems with the standard's underlying data model or XML schema. Still, several revisions to the standard have been made in order to make corrections for these design problems. Due to the limited resources available to maintain the standard, the troubleshooting and updating of the forms proved to be beyond the resources available. Each revision caused issues with the users because the data (that was unaffected by the bugs in the implementation) was in the containers that were depreciated. In the end, the design team decided that no corresponding tool would be included with the v2.0 standard. It was deemed better for official solution providers to create working implementations for the standard, since they would be better able to provide end user support. Equally important, by separating the data exchange specification from the implementation, updates to the tools can be made without effecting existing XML files.

Solution: IPC 1752 - System Approach

The long-term goal of the 1750 series of standards is to provide a framework for declaring any information that must be exchanged between a supplier and the customer. This framework presently has two sectionals (the individual numbered standards that make up the IPC 1750 series of standards); material data and manufacturing data, but other sectionals including process chemical data and manufacturing capability data are being developed. Additionally, several existing standards will be converted for use with the framework, including: IPC-1730, which will become IPC-1753-Laminate Capability and process declaration; IPC-1710, which will become IPC-1754-Printed Boards Capability and process declaration-Boards; and IPC-1720, which will become IPC-1755-Assembly Capability and process declaration-Assembly.

This framework is based on a system design philosophy focused on the entire supply chain's information requirements. By modeling the domain using the Unified Modeling Language and then using software tools to convert the model into an XML schema that defines the XML structure for the data exchange, the resulting standard accurately addresses the stakeholder requirements. Because the UML model can also be converted into database structures and programming code toolkits, it is easily integrated into the supply chain data management systems.

While the entities (called classes) used to describe objects in the UML model can contain both attributes (discrete pieces of data) and operations (simple tasks that may be performed by the object), no operations are defined, as the objects (which become elements in the XML schema) are only used as data containers. The containers are used to organize and hold the different pieces of data that are then exchanged between stakeholders in the supply chain. This approach simplifies the implementation of the model and XML schema. Ideally the model, and therefore the standard, would include the operations as well, but due to practical limitations, this will be left for a future version. The diagram in figure 2 is a high-level view of the 175x v2.0 design that shows the modular structure of version 2.0. It shows the major top-level objects and the relationships between them. It does not show the data fields themselves (only showing a generic "attribute" as a placeholder) due to the sheer number of attributes in the standard and the limited space to describe the attributes here. For the fully detailed 175x v2.0 UML model and the associated schema, please contact the author directly.

Major Changes in Version 2.0

For version 2.0 of the 1750 series of standards, two major types of changes were made; changes to fulfill new function requirements requested by industry, and changes to the structure to fulfill the requirements for a modular supplier declaration framework. The functional changes include the support for new and upcoming regulations, multiple part reporting in one declaration, and support for digital signatures. The changes to support a modular framework include moving all material declaration related data into one element, restructuring the Product element, placing all business information in a separate BusinessInfo1751 element and moving the manufacturing information from within the 1752 material information to its own ManufacturingInfo1756 element reflecting the new 1756 sectional.

Multiple parts (products)

One of the most requested features for v2.0 was the ability to declare multiple parts in one declaration. Since "multiple parts" means different things to different people, the first step was to define different categories of multiple parts. To further generalize, IPC 1752 v2.0 treats everything as a "product" (the XML element is called Product) and things that compose the product are sub-products (the XML element is called SubProduct. This notation will be used through the rest of the paper. The team came up with four basic groupings; same mass and material content, different mass and same material content, same mass and different material content, different mass and different material content.

Grouping one is a grouping of products where all of the items are identical in both body weight and material content. This scenario describes a family of products. Examples include a family of resistors with the same physical dimensions but different resistance values, and a family of screws (or nuts, bolts, etc.) with different thread pitch or head type.

Grouping two is a grouping of products where the products have different weights but are identical in material content. This scenario describes a grouping of products that are composed of the same materials, but vary in body size or number of repeatable products. Examples include a group of connectors with different pin counts, chassis of different sizes made of same materials, and uncoated wire of different gauge.

Grouping three is a grouping of reported products where all the items have the same weight value, but for each product the material content is different. This scenario is possible if the product is produced in different manufacturing facilities with different raw or processed material sources. A good example is an IC with multiple assembly locations, where the SubProducts composing the IC (wire leads, pins, case, etc.) are purchased from a variety of locations, and each location has differing content material content for the SubProducts due to different material sources.

Grouping four is a grouping of products where the products have different weights and different material content. This scenario will not involve families of products, but involve a group of products with no physical similarities between them. Instead the commonality is logical, such as all the products that a supplier provides to a particular company.

The BOM (bill of materials) scenario is a special case of the category 4 grouping in that the products declared may have different weight and material content but are related by their association within a product. In this case, the products are not placed in a flat list (i.e. Products all at the top level), but are associated with parent products and child products. In the XML instance, there is a Product element which may have SubProduct elements which may have SubProduct elements, etc. This recursive structure allows the structure of a product to be described.
While v2.0 will support all four categories, not every category is supported in each type of declaration. The three types of declarations (yes/no, part level, material level) each support different levels of multiple parts.

QueryList
The specific legislation declaration information has been restructured and generalized to support additional legislation and custom declarations. By using a statement query with a true/false response, even a custom declaration may be checked for validity. The new container is the QueryList element which allows a requester to define custom queries which may be used in addition to the queries specified in the standard. The QueryList element is a container for a list of queries defined either in the 175x sectionals or by the requester. These queries are phrased as statements and each query has a Response element with a Boolean (true/false) attribute associated with it.

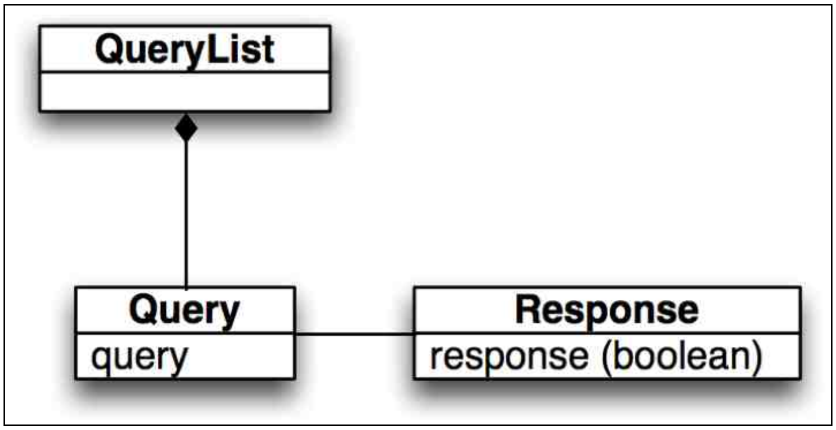

Figure 1 The Query - Response structure

NOTE: At the time of this writing, the query/response structure has not been finalized and may change before publication.

Modularity
To support future data needs and provide the flexibility to meet the different approaches to material data collection, a modular structure is a necessity. In v2.0, the 1751 business information and 1752 material information are placed in separate containers. Because one goal of the 1750 series is to generalize each section as much as possible to support different supplier requirements, the manufacturing information has been split into its own container as well. This new sectional is IPC 1756 and optionally allows for more manufacturing information to be exchanged than just that associated with material declaration.

In addition to reorganizing the sectional data, an advantage of this modular approach is the ability to reuse common elements. An example of this is the Amount element which contains mass and concentration data. This element is used within the Product element, the HomogeneousMaterial element, the SubstanceCategory element, and the Substance element. Programming a database and the supporting code for manipulating the data is simplified by using this approach.

XML Signature
To address the need for traceability and authentication, the ability for the supplier to sign the XML instance has been added. A standardized method of signing XML documents (called, appropriately enough, XML Signature) has been defined by the W3C. This recommendation defines the signature element for use in an XML document. One of the features of XML Signatures is the ability for the signature to be included in the document that is being signed, so it does not have to be included in a separate file or wrapped around the original XML file that was signed. Additionally, the XML Signature also defines the Canonicalization method, which defines the method used for formatting the file prior to signing it. This is

important since whitespace in an XML document is syntactically insignificant. Since the whitespace does affect the signature of the document, a method of formatting the document is needed.

High Level Model

The following figure and descriptions explain the high level structure of the v2.0 data exchange. The model is a simplified format based on an UML class diagram. The boxes (or classes) describe the different containers and the lines between them show how the containers are associated with each other. The lines between the boxes represent associations between the classes. The numbers next to a particular class represent the multiplicity (in XML terms, the number of times an element can appear within a parent element). The classes define the types of XML elements used in a 175x XML file and the associations and multiplicities describe the relationships between the XML elements in the file.

In trying to understand the diagrams it is helpful to think of the XML elements in a file as being containers. These containers hold the data for a 175x XML data exchange. The containers are sometimes grouped together in other "parent" containers to help organize the data. So the diagram describes what type of data the containers hold (including both simple data such as a name or date and containers).

To simplify the structure, in the XML schema implementation the names of the classes are used for the element labels unless a class is used more than once so the labels are left off the association lines unless the association label is different than the child class name. For example there is a Product class in the Figure 2 diagram there is a Product class and an associated SubProduct class (both of class Product). This means both elements have the properties of the Product class even thought they have different names. In this particular case the SubProduct is a Child of Product which means in the 1752 model a Product container can contain SubProducts that have the properties of Products.

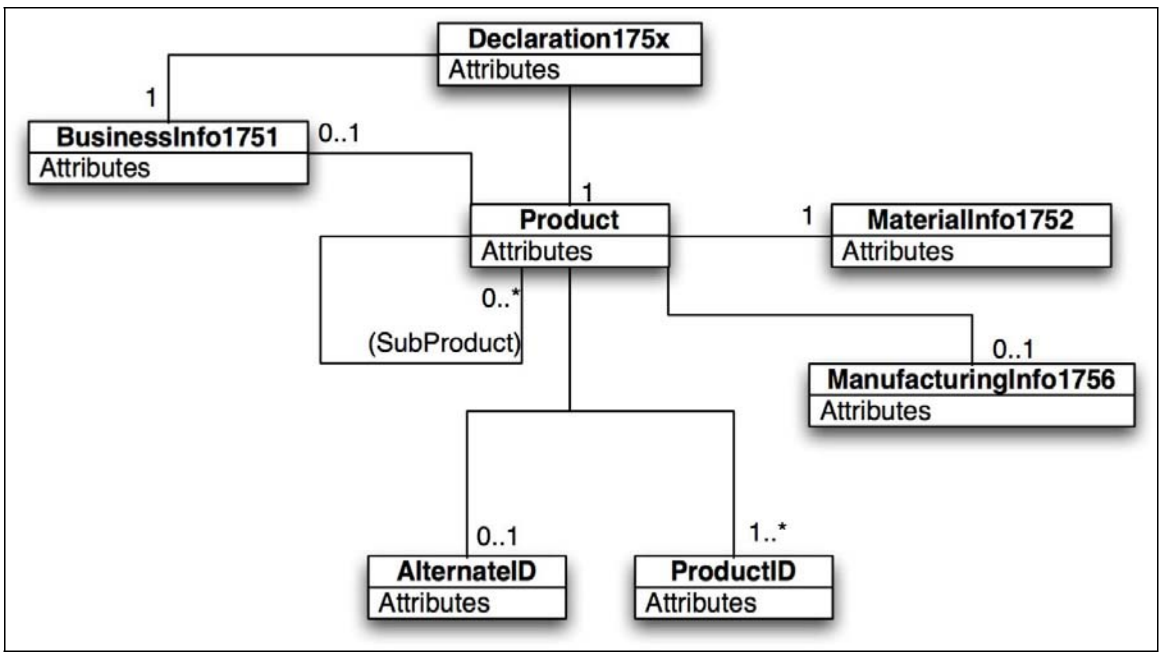

Figure 2 High level data model for IPC 1752 and 1756 data exchange

High Level Model Description

Each declaration will include a Declaration175x element that is the top level container for all 1750 series declarations and one Business1751 element to contain the information necessary to perform the actual data exchange. The Product element is required for all product (rather than manufacturing capability) declarations, and includes material information and manufacturing information related to the product. The ProductID element is used to uniquely identify the products being declared. If the declaration is for a grouping of products, there may be more than one ProductID, and all products associated with the ProductIDs are covered by the declaration. Finally, the AlternateID is also associated with the Product and is a way for the supplier to suggest another product if the one requested is not suitable.

MaterialInfo1752 and ManufacturingInfo1756 contain, respectively, the 1752 sectional information on the material content and the 1756 sectional information on manufacturing parameters for the product being declared.

Element Description
Following are general descriptions of the major elements, as shown in the high-level model. These are designed to give an idea of how the version 2.0 standard is designed and help users understand the structure. For specific details including the attributes associated with each element, please see the published IPC 1750 series of standards.

Declaration175x - The Declaration175x element is the top-level element of the XML file. There is only one Declaration175x element per 175x XML instance. This element is used for all 175x sectionals.

Business1751 - This element holds the business information necessary for the declaration to be exchanged between trading partners. There is one Business1751 element required within the Declration175x element, but additional Business1751 elements may be added under the Product element, allowing multiple declarations to be rolled up into one multi-level declaration. The same element is used for all 175x sectionals.

Product - The Product element is the element that all product-related elements are associated with (so far this is only the 1752 and 1756 sectionals) within the declaration. There may be multiple products associated with a single declaration. There may be one or more SubProducts (of type Product) contained within each Product element. The Product element only exists if the sectionals being declared are related to a product (instead of a manufacturing site).

SubProduct – the SubProduct is an element of type Product that is a subpart or subassembly of the Product being declared. A SubProduct element may also contain more SubProduct elements, allowing as many levels as needed to be described. A SubProduct element may not exist without a parent Product element.

Material1752 - This element holds the material declaration data for the product that it is associated with. This element may hold three different levels of data, corresponding to the Yes/No data, JIG-level data, and full material data levels of the v1.0 standard. This is only used for the 1752 sectional.

ManufacturingInfo1756 - The manufacturing information included in v1.0 has been expanded and moved to its own sectional standard. This information is contained within the ManufacturingInfo1756 element. There may be one ManufacturingInfo1756 element associated with each product. This is only used for the 1756 sectional.

ProductID - The ProductID identifies the Product that is being described. In situations where the declaration covers more than one product (see multiple parts), there may be more that one ProductID element associated with a Product.

AlternateID - The AlternateID allows a supplier to suggest a different part to replace the requested part. The AlternateID is only for informational purposes and product information related to the product identified using the AlternateID is NOT reported within the declaration. Product data for the product described by the AlternateID must be reported in a separate declaration.

Conclusion
As the electronics manufacturing environment changes, the supporting standards must adapt. In the area of environmental regulation the regulations are changing rapidly, and industry must work very hard to keep pace. The 2.0 revision to the IPC 175x series of supplier declaration standards is a response to these changing needs of industry. Not only does it supply the data needed to meet new regulations, but input from industry has been used to improve the functionality of the standard resulting in a specification that is extremely well matched to the domain. The standard provides the level of complexity necessary for the most sophisticated user while at the same time it is simple to use in basic data management systems. Additionally, the standard is designed to easily adapt to future requirements with a minimum of effort. As part of a holistic approach to supplier–customer data exchange, this series of standards provides the framework to assist the electronics supply chain to exchange needed data now and in the future.

Citations and References

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