Using Controlled Vocabularies to Manage Resource Relationships: The KMODDL Experience

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Abstract:

The Kinematic Models for Design Digital Library (KMODDL) exemplifies digital collections in which groups of objects are versions of the same resource and which resources are related to one another taxonomically. Other objects in the collection are supplementary materials that explicitly cite the primary KMODDL resources. To manage the complex relationships among KMODDL objects while maintaining the DC one-to-one principle, metadata developers established controlled vocabulary encoding schemes that linked related objects. The solution implemented enables users to find all versions of a resource and all supplementary materials that cite the resource in a single search.

Keywords:

Application profiles, bibliographic relationships, controlled vocabularies, encoding schemes, Functional Requirements for Bibliographic Records, kinematics.

1. Introduction

Digital collections containing clusters of objects that are versions of the same resource challenge Dublin Core metadata element set developers who want to adhere to the DC one-to-one principle, i.e., to create one record for each version, while still enabling users to discover all versions of a resource with relative ease.(1) Three approaches to meeting this challenge present themselves. In one approach, developers can sidestep the one-to-one principle by first creating a resource-level object such as an HTML page that brings all versions of the resource together and then creating metadata records that describe and point to that object. This approach is problematic because it makes it difficult to associate descriptions of version-specific characteristics with the versions to which they pertain. In a second approach, developers can create a record for each version of a resource and then use instances of the DC Relation element to present users with access information for other versions of the resource. This approach can be somewhat effective, but it is cumbersome and potentially unreliable because it loads each version-specific record with multiple Relation instances that may be difficult to maintain accurately over time and that still make it difficult if not impossible for users to discover all versions of the resource in a single search. Or, following a third approach, developers can implement controlled vocabularies to represent resources with multiple versions and create records for each version of a resource that contain the vocabulary term for the resource. This approach only requires that each version-specific record contain a single Relation element instance that points to the vocabulary term for the resource. The approach does not involve maintaining multiple Relation occurrences and, most importantly, enables users to retrieve all versions of a resource through a single search on the vocabulary term for the resource.

Developing a Dublin Core element set application profile for the Cornell University Library for the Kinematic Models for Design Digital Library (KMODDL) afforded the members of the Cornell Metadata Services team an opportunity to apply this third vocabulary-based approach to a fascinating digital collection whose primary resources are all available in various versions.(2) Moreover, KMODDL is remarkable because the multi-versioned resources it contains are related to one another taxonomically. And, to add another layer of complexity, KMODDL contains secondary resources that reference one or more of the primary resources in the collection. The present case study describes the steps that the Metadata Services team took to develop a DC application profile that would enable users to retrieve the interrelated resources in KMODDL. A description of KMODDL resources follows.

2. KMODDL resource categories

KMODDL is an open access, multimedia digital library for learning about and teaching kinematics, which KMODDL developers define as the geometry of pure motion. KMODDL developers have designed it as a pedagogical space for use by teachers, researchers, students at a range of educational levels, and other young and adult learners. The core collection in KMODDL, and the collection for which Metadata Services developed the application profile described here, is Cornell University's Reuleaux Collection of Mechanisms and Machines. The collection comprises more than 200 mechanisms developed by Franz Reuleaux, the founder of kinematics, to study the principles of mechanical motion. KMODDL provides online access to the Reuleaux Collection via these categories of digital resources:(3)

- still and interactive moving images of Reuleaux mechanisms
- computer simulations of mathematical relationships associated with the mechanisms' movements
- stereolithography files for "printing" working physical replicas of the mechanisms
- tutorials that use the mechanism images and simulations for classroom instruction
- historical and theoretical texts that refer to the Reuleaux mechanisms
- biographical sketches of significant figures in the history of machines and the field of kinematics

To facilitate browsing the images, simulations, and stereolithography files that constitute the digital versions of the Reuleaux mechanisms, KMODDL makes extensive use of the Voigt/Reuleaux Classification of Mechanisms.

3. Voigt/Reuleaux Classification of Mechanisms

To organize and study kinematic mechanisms, Franz Reuleaux created over 800 models of mechanisms in the mid 19th century. In the 1870s he authorized a German company, Gustav Voigt Mechanische Werkstatt, to manufacture more than 300 of these models for instructional purposes.(4) By 1907, 368 models were available in the Voigt catalog, which classified the Reuleaux mechanisms using an alphanumeric scheme.(5) The Voigt/Reuleaux scheme organizes the mechanisms into twenty-five broad classes designated by single alphabetic characters and class names in the original German. The scheme then divides each class one level further, into from two to thirty-nine subclasses, with each subclass designated by a letter-number pair and the German name of the subclass.

The KMODDL site presents the Voigt/Reuleaux Classification to users in a hierarchical folder display that uses English names for the classes and subclasses.(6) Users can browse the folders and click on classes and subclasses to view the KMODDL resources associated with them. The English-language version of the first three classes of the Voigt/Reuleaux scheme as used in KMODDL appear in Figure 1 on the following page.

The categories of KMODDL digital resources described in Section 2 and the Voigt/Reuleaux Classification described in this section were the two key characteristics of the KMODDL collection that guided Metadata Services' use of controlled vocabularies in a DC application profile designed to facilitate KMODDL resource discovery. Those two characteristics led to two important steps in developing the KMODDL profile. First, metadata staff implemented a vocabulary to identify the types of resources in KMODDL, described in Section 4. Second, and more importantly, they implemented vocabularies to manage the bibliographic relationships among those resources, described in Section 5.

4. Implementing the KMODDL Type Vocabulary

To identify KMODDL resource types, Metadata Services staff interviewed KMODDL developers about the resources they had targeted for inclusion on the site. First, the developers wanted to describe the original mechanism *models* that Voigt had built to Reuleaux's specifications. The models themselves of course would not be accessible, but developers felt KMODDL users would find details of their features important.

In addition, developers wanted to provide access to *stereolithography files*, *still images*, *movies*, *simulations*, and *virtual reality models*, all of which were versions of the mechanisms defined by the Voigt/Reuleaux subclasses.

Other types of KMODDL resources referenced the Voigt/Reuleaux mechanisms. These included *tutorials*, *biographies*, *books*, *book sections*, *papers*, *articles*, *conference proceedings*, and *theses* or *dissertations*. Developers wanted the KMODDL site to be able to identify these resources, with the exception of tutorials and biographies, as being in either print or digital formats.

In order to manage these KMODDL resource

```
A. Lower Element Pairs
   A01   Screw Kinematic Pair
   A02   Revolute or Turning Kinematic Pair
   A03   Prismatic or Sliding Kinematic Pair
B. Higher Element Pairs
   B01   Duangle in an Equilateral Triangle
   B02   Curved Triangular Rotor in a Square Chamber
   B03   Curved Triangle in a Rhombus
   B04   Curved Triangle Variation in a Square
C. Simple Kinematic Chains
   C01   Four-Bar Linkage
   C02   Slider Crank Mechanism
   C03   Spherical Four-Bar Linkage
   C04   Slider Crank Mechanism with Higher Order Pair
   C05   Inversion of Slider Crank Mechanism with Higher Pair Joints
   C06   Slider Crank Mechanism
   C07   Simple Spur Gear Mechanism
   C08   Simple Planet and Ring Gear Wheel Train
   C09   Endless Screw or Worm Drive Mechanism
```

Figure 1. Classes A to C of the Voigt/Reuleaux Classification of Mechanisms

types, Metadata Services investigated existing type vocabularies. Finding none that had the specificity required for KMODDL resources, metadata staff defined terms in a KMODDL Type Vocabulary and established a KMODDL Type Vocabulary encoding scheme in the KMODDL application profile.(7) At the time of this writing, KMODDL Types include these terms:

KMODDL Type Vocabulary Terms

Article_Digital	Movie
Article_Print	Paper_Digital
Biography	Paper_Print
Book_Digital	Simulation
Book_Print	StereolithographyFile
BookSection_Digital	StillImage
BookSection_Print	Thesis Dissertation_Digital
ConferenceProceeding_Digital	Thesis Dissertation_Print
ConferenceProceeding_Print	Tutorial
Model	VRM

5. Implementing Voigt Identifiers and Subjects

In addition to a vocabulary to manage the types of resources in the library, the KMODDL domain also called for vocabularies to manage the relationships among KMODDL resources. As mentioned above, those relationships fall into two categories. First, models, movies, simulations, stereolithography files, still images, and virtual reality models are versions of the mechanism subclasses defined in the Voigt/Reuleaux taxonomy. Second, articles, biographies, book sections, books, conference proceedings, papers, theses and dissertations, and tutorials reference the Voigt/Reuleaux mechanisms.

Conceptual models of bibliographic relationships such as Barbara Tillett's taxonomy of bibliographic relationships and *Functional Requirements for Bibliographic Records* (FRBR) can help put the relationships shared by KMODDL resources in a broader context.(8) In Tillett's taxonomy, related bibliographic resources exhibit from among these seven types of bibliographic relationships: *equivalence*, as in the relationship between originals and their reproductions; *derivative*, as in works that are versions or adaptations of earlier works; *descriptive*, as in resources that describe or evaluate other resources; *whole-part*, as in works that are components of larger works; *accompanying*, as in resources that are issued or intended to be used together; *sequential*, as in resources such as journal issues that succeed one another over time; and *shared characteristic*, as in otherwise unrelated resources that happen to share important characteristics such as authors, titles or creation dates.(9) Using Tillett's relationship types, the KMODDL resources that are versions of the Voigt/Reuleaux subclasses exhibit derivative relationships to those subclasses insofar as they use various media to embody defining features of the subclass. Applying Tillett's taxonomy to the KMODDL resources that refer to Voigt/Reuleaux mechanisms, those resources exhibit descriptive relationships in that the books, tutorials, etc., annotate and comment on specific KMODDL mechanisms.

In applying FRBR to KMODDL, one notes first that FRBR identifies an intellectual or artistic product as one of four entities: a *work*, which is a distinct intellectual or artistic creation; an *expression*, a realization of a work; a *manifestation*, a physical embodiment of an expression of a work; or an *item*, which is a single instance of a manifestation.(10) FRBR expresses the manifestation-to-expression-to-work relationship by saying that a manifestation physically embodies an expression that realizes a work.(11) Thus by applying FRBR terminology to KMODDL resources, a Voigt model (manifestation) embodies Reuleaux's design (expression) of a particular type of mechanism (work).(12)

FRBR also addresses the type of relationship that exists between KMODDL descriptive resources (articles, books, tutorials, etc.) and the Voigt/Reuleaux mechanisms to which they refer. FRBR treats this type of relationship as a work-to-work relationship in which the descriptive resource serves as a *supplement* to the mechanism because, within the sphere of KMODDL, it is intended to be used in conjunction with the mechanism.(13)

Therefore, using FRBR's logic and language, a movie, simulation, stereolithography file, or still image of a slider crank mechanism is a manifestation of the work that is C06, Slider Crank Mechanism, of the Voigt/Reuleaux Classification. Using the language of both FRBR and Tillett, the vocabulary terms "C06" and "Slider Crank Mechanism" represent the work of which models, simulations, stereolithography files, and moving or still images are derivatives. Similarly, the Voigt/Reuleaux alphanumeric identifier and subclass name can represent the work to which descriptive, supplementary resources such as articles, books, and tutorials refer. The Voigt/Reuleaux identifiers and class and subclass terms can thus become powerful tools to enable users to find all KMODDL resources that are manifestations derived from a given mechanism and/or that are supplementary resources that describe a given mechanism.

To that end, Metadata Services staff established two controlled vocabulary encoding schemes in the application profile they developed for KMODDL. First, they declared the Voigt-1 ID encoding scheme.(14) (They named the scheme Voigt-1 because the Voigt catalog also contains a second classification scheme, which has not yet been implemented in KMODDL.) Voigt-1 ID refers to Voigt/Reuleaux alphanumeric identifiers such as A01, A02, A03, B01, and B02. Second, they established the Voigt-1 encoding scheme for the DC Subject element.(15) Voigt-1 refers to Voigt/Reuleaux class and subclass terms such as Simple Kinematic Chains, Four-Bar Linkage, and Slider Crank Mechanism.

To be able to discuss with some specificity how these encoding schemes support user information needs in KMODDL, it useful to turn again to FRBR. FRBR identifies four generic tasks that users perform when they interact with information systems: 1) Users *find* resources that correspond to their search terms. 2) They *identify* resources, distinguishing among those with similar characteristics. 3) They *select* resources that have features that meet their needs. 4) They *obtain* resources by purchase, loan, or electronic access.(16) FRBR goes on to evaluate the relative importance of various data structures in serving these generic user tasks. Among those evaluations, FRBR identifies two basic functions of metadata records that are relevant to the use of encoding schemes in KMODDL. First, FRBR holds that metadata records should enable users to find all manifestations of a work. Second, metadata records should enable users to identify and select particular manifestations of a work based on the form or type of those manifestations.

To the extent that the Voigt-1 ID and Voigt-1 encoding schemes enable users to find all manifestations of Voigt/Reuleaux mechanisms, they fulfill the first basic function described here. In fact, the two encoding schemes complement one another with regard to searching precision and recall. Because Voigt-1 ID identifiers refer to Voigt/Reuleaux mechanisms unambiguously, using them to retrieve all resources related to a specific mechanism is extremely precise. Conversely, because many related Voigt-1 subject terms contain the same words, such as "slider" and "crank," searching the terms "slider crank" yields the high-recall result of finding resources related to a number of similar mechanisms.

Similarly, the KMODDL Type Vocabulary encoding scheme fulfills the second basic function of a metadata record named above. The KMODDL Type Vocabulary enables users to identify clearly the types of mechanism versions they have retrieved and enables them to select from among those versions based on characteristics that are important to them. Thus the three KMODDL encoding schemes are central to users' ability to find, identify, and select resources in KMODDL.

6. Putting the pieces together: Assembling and implementing the KMODDL application profile

With the three KMODDL encoding schemes established, Metadata Services staff created an application profile containing detailed descriptions and implementation guidelines for all elements, element refinements, and encoding schemes used in KMODDL.(17) The KMODDL profile follows the Dublin Core Application Profile Guidelines as drafted by the European Committee for Standardization.(18)

Because KMODDL is part of the National Science Digital Library, which requires Dublin Core Metadata Element Set (DCMES) output, Metadata Services staff elected to use the DCMES as the base element set for describing KMODDL resources. For guidance in applying the DCMES, metadata staff referred to the DC-Library Application Profile (DC-Lib), which addresses DCMES usage in libraries and library-related applications.(19) They modified the DC-Lib profile for KMODDL because not every element, element refinement, or encoding scheme used in DC-Lib was necessary for KMODDL resources. In the end, the metadata terms (elements, element refinements, and encoding schemes) adopted by KMODDL come from four of the namespaces used in DC-Lib:

- Dublin Core Element Set Version 1.1 [http://purl.org/dc/elements/1.1/]
- Dublin Core Terms [http://purl.org/dc/terms/]
- Dublin Core Type Vocabulary [http://purl.org/dc/dcmitype/]
- MODS Version 3 [http://www.loc.gov/mods/v3]

KMODDL metadata developers also selected a few terms from these namespaces:

- Art & Architecture Thesaurus [http://www.getty.edu/research/conducting_research/vocabularies/aat]
- DLESE [http://www.dlese.org/]
- MARC Code List for Organizations [http://lcweb.loc.gov/marc/organizations/]

And, in order to implement the KMODDL Type Vocabulary, Voigt-1, and Voigt-1 ID encoding schemes formally, Metadata Services staff established these KMODDL namespaces:

- KMODDL [http://www.purl.org/KMODDL/kmoddl_v1.01.xsd]
- KMODDLType


```xml
<kmoddl_dc:kmoddl schemaVersion="1.01.000" xmlns:kmoddl_dc="http://purl.org/kmoddl/kmoddl_v1.01/"
xmlns:dc="http://purl.org/dc/elements/1.1/" xmlns:dct="http://purl.org/dc/terms/"
xmlns:dlese="http://www.dlese.org/Metadata/adn-item/0.6.50/vocabs" xmlns:mods="http://www.loc.gov/mods/v3"
xmlns:aat="http://www.getty.edu/research/conducting_research/vocabularies/aat"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:schemaLocation="http://purl.org/kmoddl/kmoddl_v1.01/
http://www.purl.org/KMODDL/kmoddl_v1.01.xsd">
    <dc:title>Slider Crank Mechanism</dc:title>
    <dct:alternative xml:lang="de">Verminderte konische Schubkurbelkette</dct:alternative>
    <dc:creator>Reuleaux, Franz</dc:creator>
    <dc:creator xml:lang="de">Gustav Voigt Werkstatt</dc:creator>
    <dc:publisher>Cornell University</dc:publisher>
    <dc:subject xsi:type="kmoddl_dc:Voigt1">Simple Kinematic Chains</dc:subject>
    <dc:description>See discussion for model C02. In this model, the link with the sliding pin is fixed. If this
    were an engine slider crank, the cylinder would oscillate as the piston moved up and down. Such a
    design for an oscillating steam engine was used by William Murdoch in 1785. Murdoch was employed by
    Boulton and Watt and made many improvements to Watt's inventions as well as several inventions of his
    own.</dc:description>
    <dc:date xsi:type="dct:W3CDTF">1882</dc:date>
    <dc:type xsi:type="dct:DCMIType">PhysicalObject</dc:type>
    <dc:type xsi:type="kmoddl_dc:KMODDLType">Model</dc:type>
    <dct:extent>Base: Width x Depth [200,89] mm; Overall: W x D x Height [223-307,110,143-177]
    mm</dct:extent>
    <dct:medium xsi:type="aat:AAT">cast iron; brass; wooden pedestal</dct:medium>
    <dc:identifier xsi:type="dct:URI">http://kmoddl.library.cornell.edu/model.php?m=13</dc:identifier>
    <dc:identifier xsi:type="kmoddl_dc:Voigt1-ID">C06</dc:identifier>
    <dct:hasVersion
    xsi:type="dct:URI">http://kmoddl.library.cornell.edu/resources.php?id=176</dct:hasVersion>
    <dct:hasVersion xsi:type="dct:URI">http://kmoddl.library.cornell.edu/resources.php?id=1070
    </dct:hasVersion>
    <dct:isReferencedBy xsi:type="dct:URI">http://kmoddl.library.cornell.edu/bib.php?m=1</dct:isReferencedBy>
    <dct:isReferencedBy xsi:type="dct:URI">http://kmoddl.library.cornell.edu/bib.php?m=2</dct:isReferencedBy>
    <dct:isReferencedBy xsi:type="dct:URI">http://kmoddl.library.cornell.edu/tutorials/01/</dct:isReferencedBy>
    <dct:educationLevel xsi:type="dlese:DLESEgradeRangeType">General public</dct:educationLevel>
    <dc:rights>For educational use only. All rights reserved by the contributor(s) and publisher(s).</dc:rights>
    <mods:physicalLocation authority="marcorg" xsi:type="mods:sourceType">NIC</mods:physicalLocation>
</kmoddl_dc:kmoddl>
```


Figure 2. KMODDL record for Voigt/Reuleaux model C06, Slider Crank Mechanism

[http://kmoddl.library.cornell.edu/schemas/kmoddltype_v1.01]

In applying terms from the namespaces listed above to KMODDL resources, metadata staff recognized the need to treat different resource types differently. They divided KMODDL resources into two groups, those that were derivatives of Voigt/Reuleaux mechanisms and those that were descriptive resources that referred to mechanisms. Working within the two resource groups, metadata staff then clustered resource types with shared characteristics and created record exemplars for the type clusters. Using this approach, metadata staff created three exemplars for these clusters of mechanism derivatives:

- Model
- Movie, StillImage, Simulation and VRM
- StereolithographyFile

Next, they created four exemplars for these clusters of descriptive resources:

- Article_Digital, Book_Digital, BookSection_Digital, ConferenceProceeding_Digital, Paper_Digital, Thesis/Dissertation_Digital
- Article_Print, Book_Print, BookSection_Print, ConferenceProceeding_Print, Paper_Print, Thesis/Dissertation_Print
- Biography
- Tutorial

With regard to the implementation of KMODDL controlled vocabulary encoding schemes in the application profile, metadata staff again treated mechanism derivatives and descriptive resources differently. Further, they treated models differently from other mechanism derivatives. Because the Voigt/Reuleaux models are the centerpieces of the Reuleaux Collection in KMODDL, metadata developers elected to construct metadata records for models that treat them as "stand-ins" for the Voigt/Reuleaux mechanism subclasses they embody. To that end, records for models use the Voigt1-ID encoding scheme with the DC Identifier element. The models' preferred status in KMODDL is also reflected in model records by DC HasVersion term instances that contain KMODDL Uniform Resource Identifiers (URIs) for other derivatives of the same Voigt/Reuleaux subclass and DC IsReferencedBy term instances that contain KMODDL URIs for descriptive resources that refer to that subclass. And, in order to group models within Voigt/Reuleaux classes, records for models include instances of DC Subject, qualified by the Voigt1 scheme, that contain the name of the Voigt/Reuleaux class to which the model belongs. To illustrate these characteristics of model records, the KMODDL record for the Voigt/Reuleaux model of C06, Slider Crank Mechanism, appears in Figure 2 on the preceding page.

For other mechanism derivatives, KMODDL records include a DC IsVersionOf term instance that uses the Voigt1-ID encoding scheme and contains the

```
<kmoddl_dc:kmoddl schemaVersion="1.01.000" xmlns:kmoddl_dc="http://purl.org/kmoddl/kmoddl_v1.01/"
xmlns:dc="http://purl.org/dc/elements/1.1/" xmlns:dct="http://purl.org/dc/terms/"
xmlns:dlese="http://www.dlese.org/Metadata/adn-item/0.6.50/vocabs" xmlns:mods="http://www.loc.gov/mods/v3"
xmlns:aat="http://www.getty.edu/research/conducting_research/vocabularies/aat"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:schemaLocation="http://purl.org/kmoddl/kmoddl_v1.01/
http://www.purl.org/KMODDL/kmoddl_v1.01.xsd">
    <dc:title>Slider Crank Mechanism</dc:title>
    <dc:contributor>Loeffler, Kent</dc:contributor>
    <dc:publisher>Cornell University</dc:publisher>
    <dc:description>In this model, the link with the sliding pin is fixed. If this were an engine slider crank, the
    cylinder would oscillate as the piston moved up and down. See also discussion about model
    C02.</dc:description>
    <dc:type xsi:type="dct:DCMIType">MovingImage</dc:type>
    <dc:type xsi:type="kmoddl_dc:KMODDLType">Movie</dc:type>
    <dc:format xsi:type="dct:IMT">video/quicktime</dc:format>
    <dct:extent>193 Kb</dct:extent>
    <dct:extent>320 x 212 pixels</dct:extent>
    <dc:identifier xsi:type="dct:URI">http://kmoddl.library.cornell.edu/resources.php?id=176</dc:identifier>
    <dct:isVersionOf xsi:type="dct:URI">http://kmoddl.library.cornell.edu/model.php?m=13</dct:isVersionOf>
    <dct:isVersionOf xsi:type="kmoddl_dc:Voigt1-ID">C06</dct:isVersionOf>
    <dct:educationLevel xsi:type="dlese:DLESEgradeRangeType">General public</dct:educationLevel>
    <dc:rights>For educational use only. All rights reserved by the contributor(s) and publisher(s).</dc:rights>
</kmoddl_dc:kmoddl>
```

Figure 3. KMODDL record for a movie of Voigt/Reuleaux model C06, Slider Crank Mechanism

```xml
<kmoddl_dc:kmoddl schemaVersion="1.01.000" xmlns:kmoddl_dc="http://purl.org/kmoddl/kmoddl_v1.01/"
xmlns:dc="http://purl.org/dc/elements/1.1/" xmlns:dct="http://purl.org/dc/terms/"
xmlns:dlese="http://www.dlese.org/Metadata/adn-item/0.6.50/vocabs" xmlns:mods="http://www.loc.gov/mods/v3"
xmlns:aat="http://www.getty.edu/research/conducting_research/vocabularies/aat"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:schemaLocation="http://purl.org/kmoddl/kmoddl_v1.01/
http://www.purl.org/KMODDL/kmoddl_v1.01.xsd">
      <dc:title>History of the Growth of the Steam-Engine</dc:title>
      <dc:creator>Thurston, Robert Henry</dc:creator>
      <dc:publisher>D. Appleton</dc:publisher>
      <dc:subject xsi:type="kmoddl_dc:Voigt1">Slider Crank Mechanism</dc:subject>
      <dc:subject xsi:type="kmoddl_dc:Voigt1">Cartwright Straight-line Mechanism</dc:subject>
      <dc:type xsi:type="dct:DCMIType">Text</dc:type>
      <dc:type xsi:type="kmoddl_dc:KMODDLType">Book_Digital</dc:type>
      <dc:identifier xsi:type="dct:URI">http://kmoddl.library.cornell.edu/bib.php?m=2</dc:identifier>
      <dct:references xsi:type="dct:URI">http://kmoddl.library.cornell.edu/model.php?m=13</dct:references>
      <dct:references xsi:type="dct:URI">http://kmoddl.library.cornell.edu/model.php?m=243</dct:references>
      <dct:references xsi:type="kmoddl_dc:Voigt1-ID">C06</dct:references>
      <dct:references xsi:type="kmoddl_dc:Voigt1-ID">S34</dct:references>
      <dct:educationLevel xsi:type="dlese:DLESEgradeRangeType">General public</dct:educationLevel>
      <dc:rights>For educational use only. All rights reserved by the contributor(s) and publisher(s).</dc:rights>
</kmoddl_dc:kmoddl>
```


Figure 4. KMODDL record for a digital book that cites Voigt/Reuleaux subclasses C06 and S34

Voigt/Reuleaux subclass of the derivative. The record also includes an IsVersionOf instance that contains the KMODDL URI of the corresponding model. Figure 3 below illustrates a KMODDL record for a movie of Voigt/Reuleaux model C06, Slider Crank Mechanism.

Lastly, for descriptive resources, KMODDL records use KMODDL encoding schemes in yet another way. They include DC References term instances that use the Voigt1-ID scheme and contain the Voigt/Reuleaux subclass codes for the mechanisms to which the resources refer. They also include DC Subject instances that use the Voigt1 scheme and contain the Voigt/Reuleaux subclass names of the mechanisms to which the resources refer. As an example of a KMODDL record for a descriptive resource, the record for a digital book that refers to Voigt/Reuleaux subclasses C06, Slider Crank Mechanism, and S34, Cartwright Straight-line Mechanism, appears in Figure 4 above.

8. Conclusion

KMODDL metadata staff developed three controlled vocabulary encoding schemes to manage the relationships among resources of varying types that are manifestations of a kinematic mechanism or that describe a kinematic mechanism. By implementing these encoding schemes strategically in a KMODDL application profile, staff designed metadata records for mechanism derivatives and descriptive resources that enable users to retrieve related records in a single search on a vocabulary term.

The efficacy of this vocabulary-based approach to managing resource relationships is evident in its impact on KMODDL search results displays. Performing a search on the terms “slider crank mechanism” yields a result that brings together mechanism derivatives and descriptive resources associated with those terms, as in:

Your search for slider crank mechanism resulted in 82 hits.
* 37 results in Models
* 19 results in Movies
* 6 results in Interactive Simulations
* 2 results in References
* 3 results in Stereolithography Files
* 15 results in Still Images

This results display satisfies basic metadata functionality by enabling users to find manifestations of slider crank mechanisms as well as references to them within the Reuleaux Collection. It also enables users to identify results by resource types and to select resources using those types.

The benefits of these user outcomes warrants the development effort of formally establishing controlled vocabulary encoding schemes and implementing them systematically in the context of a metadata element set application profile.

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