Designation: ~~E3012 – 16~~ E3012 – 20

Standard Guide for Characterizing Environmental Aspects of Manufacturing Processes[1]

This standard is issued under the fixed designation E3012; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide provides ~~manufacturers~~ an approach to characterize any category of manufacturing process and to systematically capture and describe relevant environmental information.

1.2 This guide defines ~~a Process Characterization Methodology that uses graphical and formal representations to support the construction of~~ the conceptual model of a unit manufacturing process (UMP) ~~information models for characterizing the environmental aspects of manufacturing processes.~~from which a formal representation can be specified.

1.3 This guide defines the graphical ~~UMP information model as being comprised of four elements (input, output, product and process information, and resources) that supports manufacturers in systematically identifying, collecting, structuring, and visualizing~~ representation of a UMP model that supports the systematic structuring and visualizing of manufacturing information.

1.4 This guide defines ~~the formal representation of the UMP information model through the use of a modeling method and language that can effectively convey the meaning and intent of processes they characterize.~~a process characterization methodology to construct UMP models that characterize the environmental aspects of the manufacturing processes under study.

1.5 This guide provides the necessary structure and formality for identifying and capturing key information ~~needs~~needed to assess manufacturing performance, yet provides no details about an actual assessment of the process performance.

1.6 This guide provides ~~an approach to link individual UMP information models together to create a network or system of UMP models that extends the characterization of environmental aspects beyond an individual process to a production system or the product itself.~~the conceptual definition for a system composed of multiple UMPs to represent a production system.

1.7 This guide may be used to complement other standards that address sustainability and the product life cycle. This guide most closely relates to the inventory component as discussed in the ISO 14040 series (ISO 14044) standards, and resource management as discussed in the ISO 55000 series (ISO 55001) standards.

1.8 *This guide does not purport to address all of the security issues and the risks associated with manufacturing information. It is the responsibility of the user of this standard to follow practices and establish appropriate information technology related security measures.*

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate ~~safety~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E2114 Terminology for Sustainability Relative to the Performance of Buildings

E2986 Guide for Evaluation of Environmental Aspects of Sustainability of Manufacturing Processes

[1] This guide is under the jurisdiction of ASTM Committee E60 on Sustainability and is the direct responsibility of Subcommittee E60.13 on Sustainable Manufacturing.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E3096 Guide for Definition, Selection, and Organization of Key Performance Indicators for Environmental Aspects of Manufacturing Processes

2.2 *ISO Standards:*[3]

~~ISO 22400-1:2014 Automation systems and integration—Key Performance Indicators (KPIs) for manufacturing operations management; Part 1: Overview, concepts, and terminology~~

ISO 14040 Environmental management—Life cycle assessment—Principles and framework

ISO 14044 Environmental management—Life cycle assessment—Requirements and guidelines

ISO 55000:2014 Asset management—Overview, principles and terminology

ISO 55001:2014 Asset management—Management systems—Requirements

2.3 *UL Standard:*[4]

ULE 880 Sustainability for Manufacturing Organizations

2.4 ~~*World Wide Web Consortium (W3C):*~~*UNECE Document:*

~~eXtensible Markup Language (XML) 1.0 Recommendation~~[5]

~~W3C XML Schema Definition Language (XSD) 1.1~~Recommendation No. 20 Codes for Units of Measure Used in International Trade

3. Terminology

3.1 Definitions of terms shall be in accordance with Terminology E2114.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *composite unit manufacturing process (UMP) model, n*—a structure representation of interactions between more than one UMP model.

3.2.1.1 *Discussion*—

Similar to a UMP model, a composite UMP model is defined with distinct inputs, outputs, product and process information, transformations, and manufacturing resources.

3.2.2 *manufacturing resource, n*—an entity that enables a manufacturing process.

3.2.2.1 *Discussion*—

Manufacturing resources include (but are not limited to) manufacturing assets, such as equipment, human operators, machinery, software, automation units, control devices, instrumentation, and tooling.

3.2.2.2 *Discussion*—

Manufacturing resources do not include natural resources since natural resources such as iron ore do not directly facilitate the completion of a manufacturing process. For other uses of the term "resource," refer to the common definition of the term.

3.2.3 ~~*composability, model composition, n*~~—the ~~ability to link~~act of linking individual unit manufacturing ~~processes~~ process (UMP) models together to create a ~~network or system of UMPs~~ composite of UMP models that can characterize the ~~environmental aspects of~~ metrics of interest of a production system or product.

~~3.2.2 *key performance indicator (KPI), n*—a quantifiable measure or a set of quantifiable measures that a company or industry uses to gauge or compare performance in terms of meeting their operational and strategic goals.~~

~~**ISO 22400-1:2014**~~

3.2.4 *unit manufacturing process (UMP), n*—the smallest element or ~~sub-process~~subprocess in manufacturing that adds value through the modification or transformation of shape, structure, or property of input material or workpiece.

3.2.4.1 *Discussion*—

[3] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[4] Available from Underwriters Laboratories (UL), 2600 N.W. Lake Rd., Camas, WA 98607-8542, http://www.ul.com.

[5] ~~http://www.w3.org/TR/xml.~~Available from United Nations Economic Commission for Europe (UNECE), Palais des Nations CH-1211 Geneva 10 Switzerland, https://www.unece.org.

A UMP is a clearly-scoped and well-defined manufacturing process that products a component, assembly, or product.

~~3.2.3.1 *Discussion*—~~

~~The UMP is a clearly-scoped and well-defined manufacturing process that produces a component, assembly, or product.~~

3.2.5 *unit manufacturing process (UMP) model, n*—structured reprsentation of the information associated with a UMP.

4. Significance and Use

4.1 This guide provides ~~manufacturers~~ a systematic approach for characterizing the environmental aspects of manufacturing processes ~~utilizing formal representations.~~based on well-established formal languages.

NOTE 1—In computer science, a formal language is a language designed for use in situations in which natural language is unsuitable as, for example, in mathematics, logic, or computer programming. The symbols and formulas of such languages stand in precisely specified syntactic and semantic relations to one another. Formal representations are derived from formal languages.

NOTE 2—A UMP model is ~~formally represented using languages~~ defined using formal languages, such as eXtensible Markup Language ~~(XML),~~ (XML) (1),[6] Unified Modeling Language ~~(UML),~~ (UML) (2), or Systems Modeling Language (SysML) to facilitate data exchange, computability, ~~sharing,~~ and communication with other manufacturing and analysis applications. These capabilities support manufacturers in evaluating, documenting, and improving performance. This guide specifically incorporates UML and XML but does not limit implementations to these languages.

4.2 This guide provides the ~~required~~ structure and formalism to ensure consistency in characterizing manufacturing processes in a computer-interpretable ~~way~~ way, thus enabling effective communication, computational analytics, and exchange of performance information.

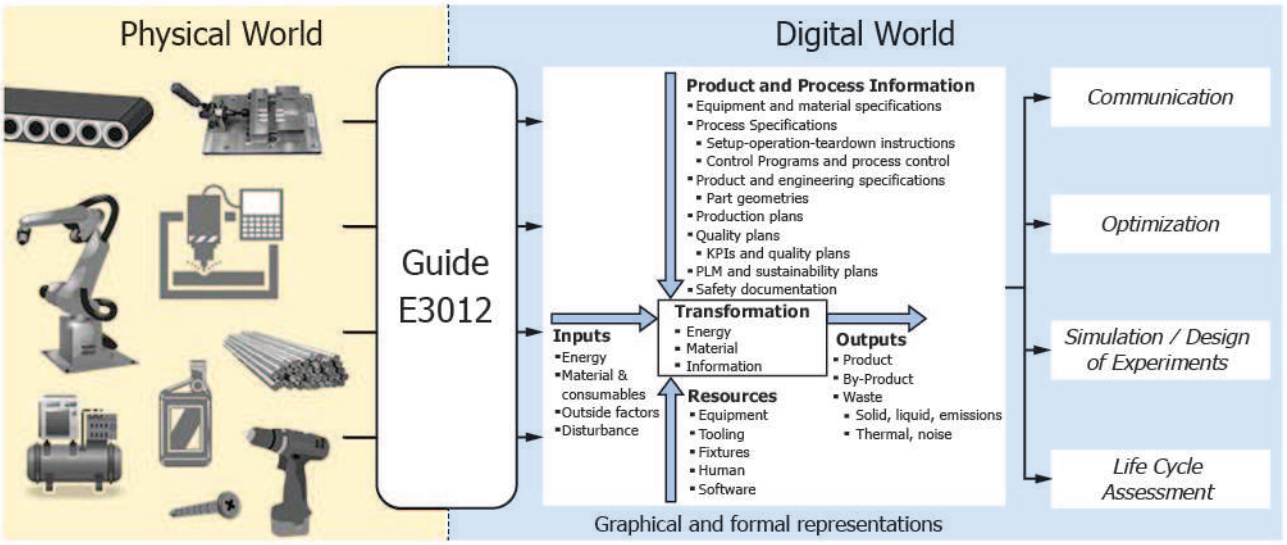
~~NOTE 2—This guide will promote new tool development that can link manufacturing information and analytics for calculating the desired environmental performance measures.~~

4.3 Fig. 1 shows how this guide is used to transition manufacturing resources, such as industrial robots, machine tools, and auxiliary devices, from the phycical world to the digital world through graphical and formal representations. In doing so, required information to perform engineering analysis, such as optimization, simulation, and life cycle assessment, is characterized in a manner that is complete, standardized, and efficient.

NOTE 3—This guide will promote new tool development that can link manufacturing information and analytics for calculating the desired environmental performance measures.

4.4 ~~The~~This guide also supports the development of tools to improve decision support capabilities while facilitating the development and extension of standardized data and information ~~bases such as Life Cycle Inventory (LCI) (ISO 14040 series).~~bases.

NOTE 4—Data collected within manufacturing enterprises can be used to build enterprise-or-sector-specific databases that complement or extend ~~LCI~~



UMPs store digital representations of physical manufacturing assets and systems to enable engineering analysis, for example, optimization, simulation, and life cycle assessments.

FIG. 1 Overview of Significance and Use of this Guide

[6] ~~http://www.w3.org/XML/Schema.~~The boldface numbers in parentheses refer to a list of references at the end of this standard.

Life Cycle Inventory (LCI) databases (ULE 880). This approach will improve the relevancy and completeness of the data while retaining key links to Life Cycle Assessment (LCA) methods.

4.5 Fig. 2 presents a road map to this guide. Section 5 describes the graphical representation of the UMP. Section 6 presents a conceptual definition of the UMP concept. Section 7 presents a step-by-step guide on how to characterize a manufacturing process using the formal methods presented in Sections 5 and 6. Section 8 describes how to create a composed system model, or a network of UMPs.

5. Graphical Representation of Unit Manufacturing Process

5.1 The graphical representation (Fig. 3) facilitates communication of manufacturing process information. It is comprised of five blocks (inputs, outputs, product and process information, transformation, and manufacturing resources) to systematically structure and visualize manufacturing information. Structured information of manufacturing processes facilitates data exchange, sharing, and communication between people and other manufacturing applications such as modeling, simulation, and analysis tools.

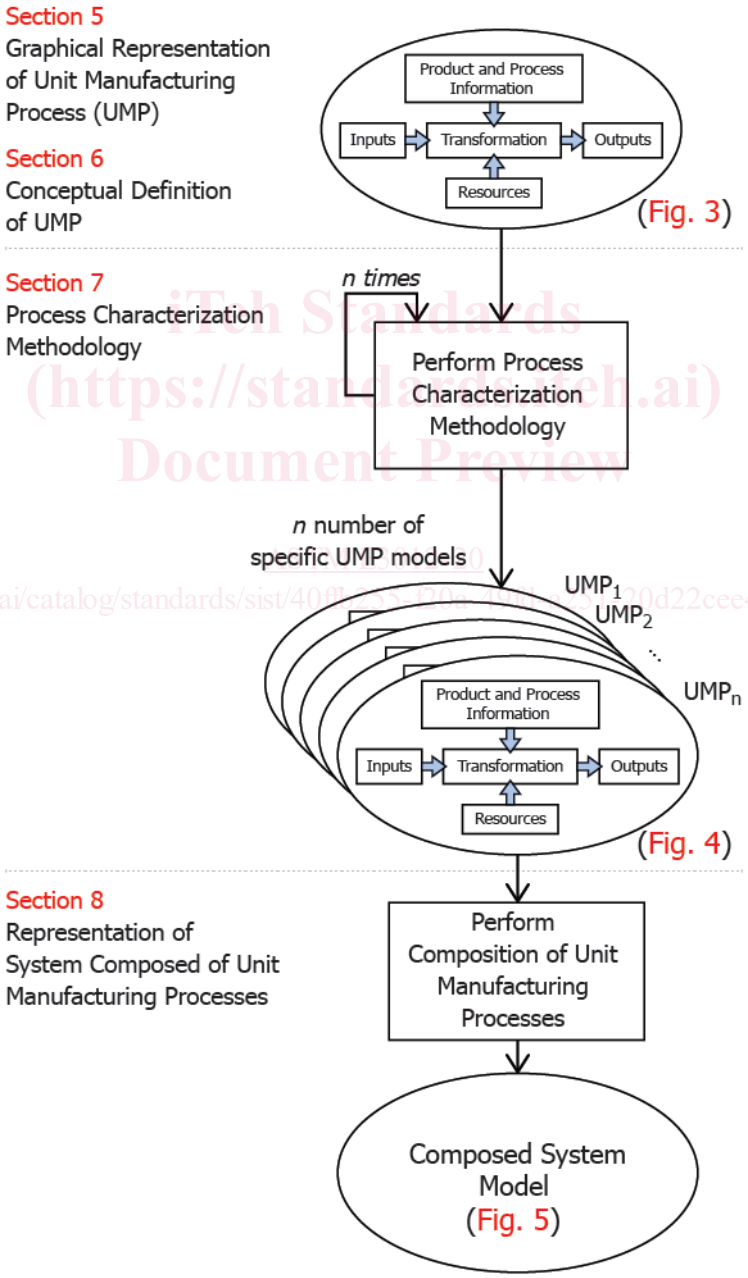


FIG. 2 Systematic Illustration of Use of UMP Representation and Process Characterization Methodology to Develop a Number of Specific UMP Models to Support Model Composition

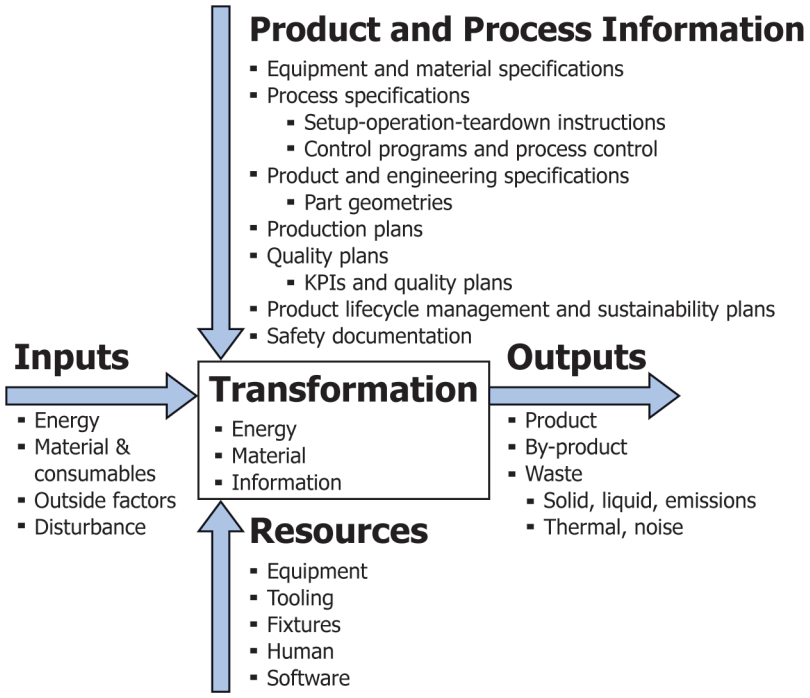


FIG. ~~1~~3 Graphical Representation of UMP Information

5.2 The contents of each of the five blocks is defined in Section 6 using UML (the Unified Modeling Language) to define a conceptual representation. From the conceptual representation, a formal representation may be defined. An example of a formal representation of the UMP implemented as an XSD schema (eXtensible Modeling Language Schema Definition) (**3**) is presented in Appendix X1. An instantiated UMP model conforming to the example XSD schema is presented in Appendix X2 as an XML document.

6. Conceptual Definition of Unit Manufacturing Process ~~Representation~~

~~5.1 The UMP representation utilizes graphical and formal methods in constructing UMP information models for characterizing the environmental aspects of manufacturing processes. Formal methods for acquiring and exchanging information will lead to better consistency in these characterizations and help establish a consolidated database of environmental measurements. Consistency of the characterizations will ensure effective communication of computational analytics and sharing of sustainability data.~~

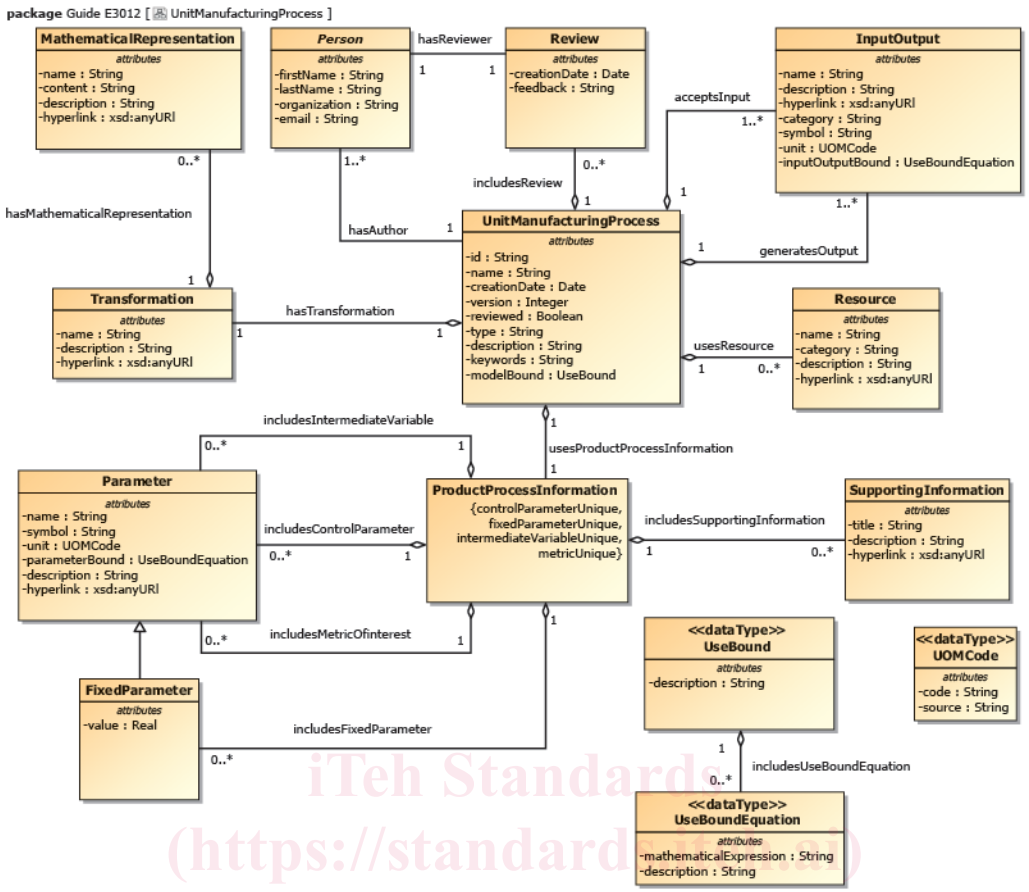
~~5.2 The graphical representation (Fig. 1) is comprised of four elements (inputs, outputs, product and process information, and resources) to systematically identify, collect, structure, and visualize manufacturing information. Structured information of manufacturing processes facilitates data exchange, sharing, and communication with other manufacturing applications such as modeling, simulation, and analysis tools. It can provide process specific information to LCI databases that will support a more detailed and accurate LCA.~~

6.1 ~~To~~Fig. 4 ~~achieve formal representations of manufacturing processes, UMPs require the adoption of a formal modeling method or language to effectively convey~~presents the conceptual definition of a UMP as a UML class diagram. Starting with the ~~*meaning*~~*UnitManufacturingProcess* ~~and intent of processes they characterize. The complete XSD schema [XML Schema Definition Language] intended for an XML [XML 1.0] implementation of UMPs is presented in~~definition in the center, UMP concepts are described as UML classes in boxes in the figure. Concept attributes are described as UML attributes, and are shown inside the boxes. Relationships between concepts are described as UML aggregations and associations, and are depicted as connecting lines in the figure. In ~~Appendix X1~~6.2~~.~~, each of the UMP concepts is defined. *Italics* are used to indicate the names of UML classes and attributes that represent that concept. Examples are given for the attributes of each concept.

NOTE 5—Information described in the conceptual definition of a UMP is purposefully written to provide flexibility in implementation. For guidance towards implementation strategies, see Appendix X1 and Appendix X2 for examples of implementation based on XML Schema. Other implementation forms may be defined.

NOTE 6—Subsections 6.2 and 6.2.1 – 6.2.5 provide examples and semantic explanation of concepts and attributes presented in the conceptual definition.

~~5.4 The basic building blocks of XML Schemas consists of elements and attributes. Elements can also contain other elements, that is, child elements. A data type defines the valid content that child elements and attributes contain.~~



~~The example shows how the output material information of one UMP model becomes the input material information of another UMP model.~~

FIG. 4 Conceptual Definition of UMP

6.2 *Unit Manufacturing Process (UMP)*—~~Table 1 presents the basic elements used in creating a UMP.~~A model of a physical process in a manufacturing ~~Fig. 1 presents the relationships between these basic elements. Besides the attributes,~~ setting that adds value through the modification or transformation of shape, structure, or property of input material or workpiece. A unit manufacturing process (defined as ~~*name,*~~*UnitManufacturingProcess*) accepts inputs (defined as ~~*description,*~~*InputOutput*), generates outputs (defined as *InputOutput*~~and~~), uses product and process information (defined as *ProductProcessInformation*), uses manufacturing resources (defined as *Resource*), has a transformation (defined as *Transformation*), includes reviews (defined as *Review*), and has authors (defined as *Person*). Some examples of a *type* of ~~the UMP, the remaining part~~ a unit manufacturing process include milling, turning, die casting, injection molding, and laser powder bed fusion. An example of the ~~*graphical*~~*description* ~~representation (~~in a~~Fig. 1~~) *UseBound* is ~~captured in the schema as child elements~~ "This model is only valid when assessing the process in the state of Ohio." An example of a *mathematicalExpression* of a *UseBoundEquation*~~and includes input (see~~ is "15 °C < temperature_ambient < 40 °C" and an example of ~~5.5.1), output~~the associated ~~(*description*5.5.2), feedback (~~ is "The~~5.5.3), product and process information (~~ model has only been validated~~5.5.4), resource information (~~ under this range~~5.5.5), and transformation (~~ of temperature conditions."~~5.5.6 and 6.5). The UMP Name must be unique among the UMP child elements.~~

6.2.1 *Input*—~~Includes all~~All physical inputs that enter the UMP, such as material (for example, raw materials or work-in-progress), consumables (for example, lubrication or forced air), ~~energy and~~ energy, as well as external factors (such as temperature, humidity, particulates, vibration, and shocks) that occur during the manufacture of a product. ~~In the schema, Inputs are described with attributes~~ An example of a ~~*name,category*~~type,~~description,category,~~ ~~and~~of ~~unit.~~an~~Type defines the material or energy used as input; it can also~~input can be material, energy, or part-in-process. An example of the ~~*be*~~*symbol* ~~"feedback" which implies that~~is "electricity_used." An example of the *code* ~~a feedback can be connected.~~ in a ~~*Description*~~*UOMCode* is ~~a free text explanation.~~ "KWH" with the ~~*Category*~~*source* ~~classifies~~ "UNECE Recommendation No. 20 - Units of Measure used in International Trade." An example of the ~~*input*~~*mathematicalExpression* ~~and can~~of a ~~*be*~~*UseBoundEquation* ~~Energy, Material, Consumables, or other external factors.~~is "electricity_used > 0" and an example ~~Unit~~of ~~quantifies~~ the ~~input~~associated *description*~~to enable conversions, for example, energy, material, or water use.~~ is "For this process to run, electricity is required."

6.2.2 *Output*—~~Includes all~~All physical outputs that exit the UMP model, such as products, by-products, waste, and emissions. Output of one UMP ~~model~~ can be an input to another ~~UMP model. In~~ UMP. An example of the ~~*schema,symbol*~~ ~~Outputs are described with attributes~~is "waste_aluminum." An example of ~~name,~~a ~~*type,category*~~ of an output can be waste, by-product, or