Integration of Energy Information for Product Assembly and Logistics Processes

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Abstract. This paper presents an on-going effort at NIST to model the energy information in assembly and logistics processes as a part of a larger sustainability improvement goal. Energy information comprises energy input, baseline energy consumption, and energy performance. An information model in this paper is developed for enabling integration of energy information in assembly and logistics processes. Based on this information model, industry will be able to share energy-related data on the overall plant level and traceable to individual processes, equipment, and suppliers. This will enable manufacturers to identify energy saving opportunities in their assembly processes and supply chains.

Keywords: Assembly Equipment Characterization, Assembly Processes Characterization, Sustainable Manufacturing and Sustainability Measurement.

1 Introduction

The manufacturing industry has recognized that improvements in sustainability will depend on the industrial capacity to increase sustainability of individual components, including parts and subcomponents of final products [1]. A key factor to improve sustainability is energy efficiency. The energy embodied in a product is an aggregation of all of the energy embodied in the products' components, expended through its manufacturing processes and logistical activities. Yet, few standard measurement methods exist to measure energy, causing different companies to measure the use of energy differently. Additionally, the amount of energy used for product assembly processes is rarely traceable to individual processes and supply chains. The total energy and resource input into an assembled product is an aggregation of all of the energy and materials required in individual processes associated with the parts, components, and subsystems that are assembled into the final product. Even though, today's information technology is capable of providing traceable measurement and aggregation methods for resource efficiency assessment of product assembly and logistics operations across supply chains, however, there is a lack of standards on measuring energy input and performance [2]. Even a methodology for characterizing energy flow in assembly processes has not been fully developed to date. Manufacturing industries, therefore, use ad hoc methods to measure energy in their assembly processes which results in uncertain predictions. A methodology is needed to standardize the measurement of energy and material efficiencies in product assembly processes. Many energy management system uses energy performance indicators based on the past energy measurement data. However, science-based energy performance indicators [3, 4] need to be developed for characterizing sustainability performance of assembly and supply chain [5] processes. Romaniw has developed an activity based sustainability assessment model using SysML [6]. The scope of his model includes the manufacturing and assembly processes, and this information model can be further extended to define concrete energy performance indicators for sustainability characterization of individual assembly and supply chain processes. In view of the above, Section 2 defines the scope and requirements of information modeling necessary to develop the methodology. Section 3 proposes a new model of integrating energy, assembly process, equipment, and logistics. Section 4 concludes possible effects of the model and points to opportunities for future work.

2 Model Requirements

The scope of our modeling is energy information in assembly processes and equipment in a factory and the energy embedded in supplied parts from third-party providers. Figure 1 shows the chosen boundary and the energy flows in a typical assembly factory with energy consumed by supply chains. Assembly equipment provides the necessary energy for the assembly processes. Some assembly processes have to be supported by auxiliary processes. The auxiliary equipment provides the

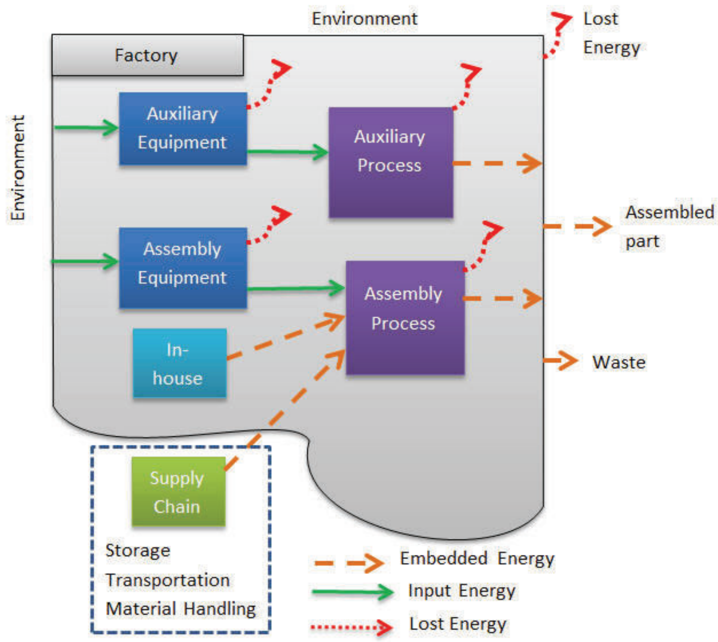

Figure 1. Energy aggregation in product assembly and supply chain

necessary energy for the auxiliary processes. Some parts are manufactured in-house, and the other parts are provided from supplier through supply chains. The total energy embodied in a final product has to include energy used to make; store; transport; assembly all its parts and components, and embedded energy in those parts; components; and factory infrastructure overhead.

The National Institute of Standards and Technology (NIST) is proposing to develop information model for integrating energy information in product assembly processes and supply chain activities (figure 1). The major requirement is to model processes, activities, equipment, and their input, output and control based on a previously developed product assembly model [7]. Describing information requirements, Figure 2 shows an activity diagram of assembly, accounting for energy performance measurement from logistic and parts handling processes in supply chains. Product assembly starts with the Original Equipment Manufacturer (OEM) (manufacturer), executing a product assembly process plan. The OEM has to acquire those parts that are not manufactured in-house by sending orders to supplier(s). The suppliers prepare or make parts for delivery or move to warehouses, consuming energy. A third party logistics provider may be included for moving and storing parts and deliver them to the OEM by the due date. The OEM starts to assemble parts into products. Note that individual parts are either supplied by supplier or manufactured in-house. Parts and subassemblies are assembled in a predefined sequence in an assembly factory. Energy

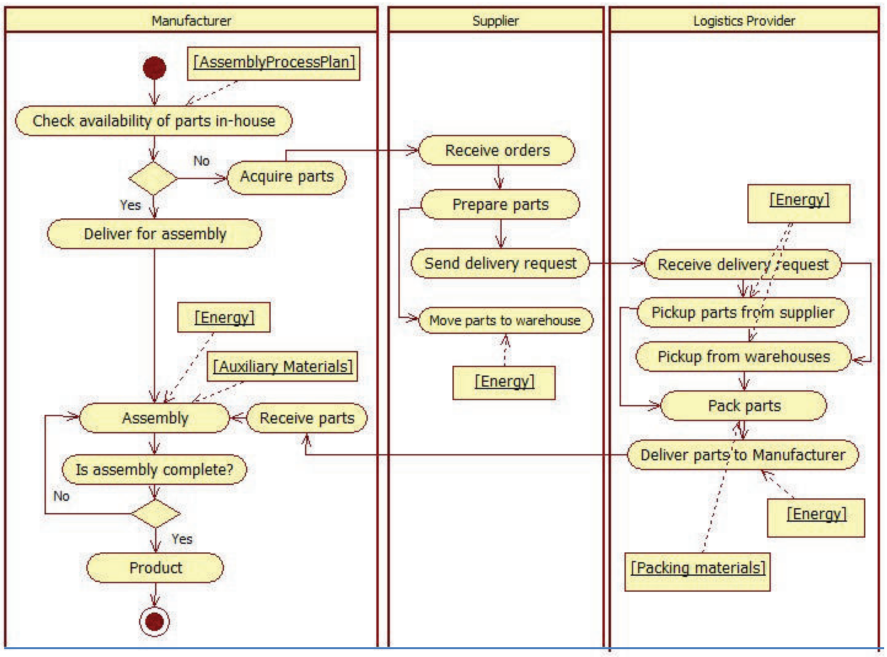

Figure 2. Assembly and logistic activities

use can be measured for each assembly process. The NIST proposed model is presented in the next section.

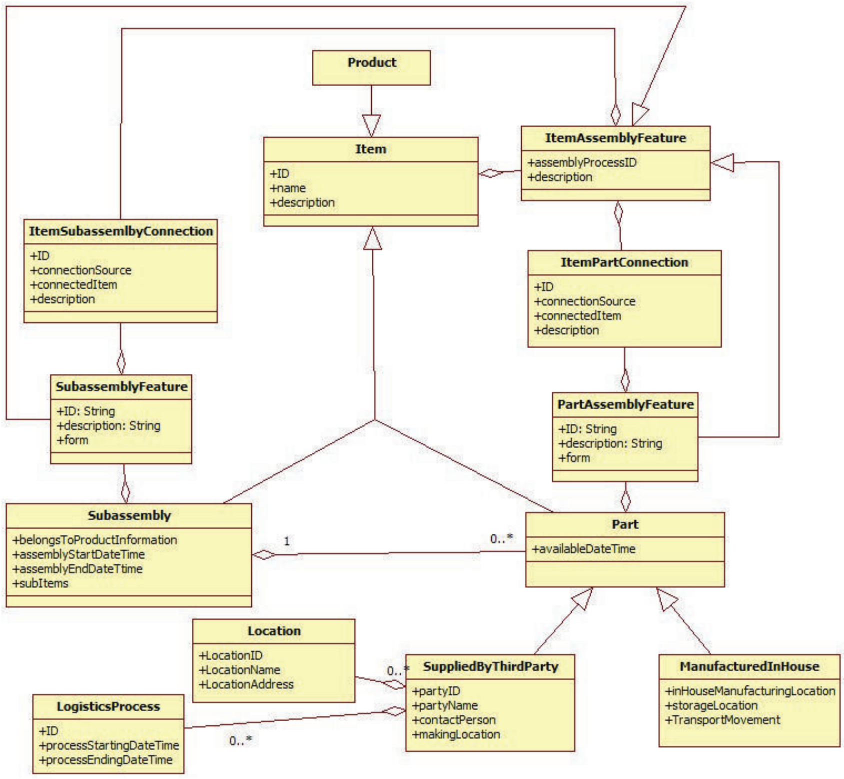

Figure 3. Item package

3 Information Model Design

The proposed information model is in class diagrams using the Unified Modeling Language (UML) [8]. The four diagrams are Item package[1], AssemblyProcess package, LogisticsProcess package, and EnergyInProcess package. The Item package is the root package in the model. Figure 3 is the diagram of all the classes in the Item Package. The **Item**[2] class is the root of the Item package. An item is a workpiece in the assembly process. For assembly, an item has assembly feature(s) that is connected to assembly feature(s) of another item. **ItemAssemblyFeature** is a class that represents assembly feature. An item can be a single part, subassembly, or product; therefore, **Product**, **Subassembly**, and **Part** are subclasses of **Item**. **Part** has **PartAssemblyFeature**, which is a subtype of the **ItemAssemblyFeature**. Part is a single object that is either supplied by a supplier in the supply chain or manufactured in-house.

[1] Package is a construct to organize model elements into a group that depicts as a file folder and can be used by other UML diagrams.

[2] Class name is in bold.

Similarly, **Subassembly** has **SubAssemblyFeature**, which is also a subtype of the **ItemAssemblyFeature**. **ItemPartConnection** is a class that describes the connection between a part and an item, which can be another part or a subassembly. Major types of connection are fit, contact, and fusion [1]. Similarly, **ItemSubassemblyConnection** is a class that describes the connection between a subassembly and an item, which can be another subassembly or a part. **Product** is class that represents the final assembly, according to the assembly process plan. **ManufacturedInHouse** is a subtype of **Part** and represents a part that is manufactured by the OEM. **SuppliedByThirdParty** is another subtype of **Part** and represents a part that is supplied by a third-party supplier. The class consists of two classes as follows. **Location** is a class that represents general information about the location of the supplier. **LogisticsProcess** is a class that describes the logistics process, which is described next.

Figure 4 is the class diagram for the LogisticsProcess Package. **LogisticsProcess**

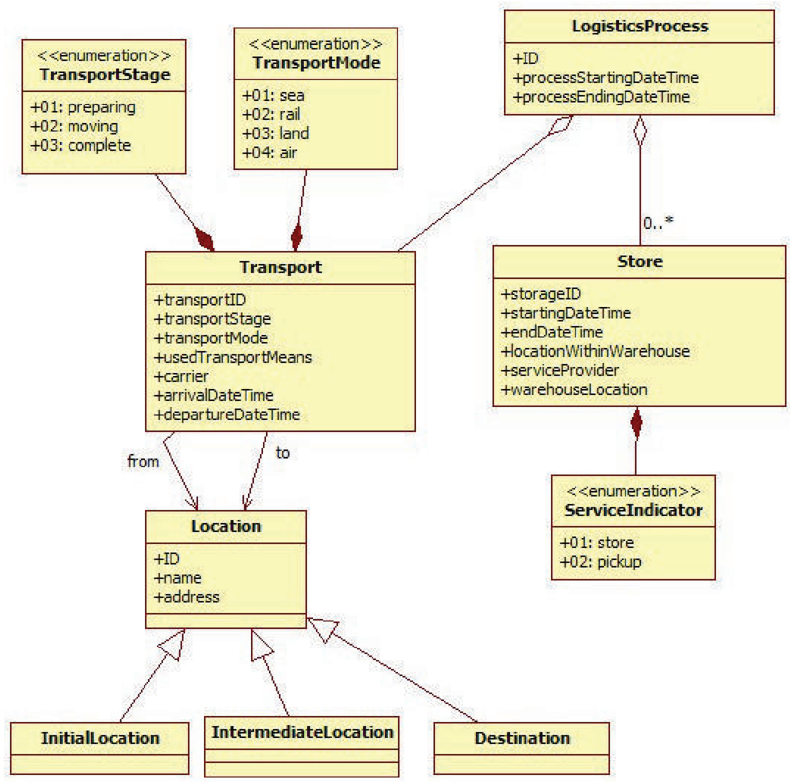

Figure 4. Logistics process package

class is the root class in the LogisticsProcess package. The class describes the logistics of parts transported from the supplier's location to the OEM location for assembly. The two major components of the class are the **Transport** class and the **Store** class. **Transport** represents the part transportation from one location to another from the supplier to the OEM**. Location** is used to indicate where a piece of equipment, a factory, a warehouse, or a supplier is. **InitialLocation**, a subclass of **Location**, describes the supplier's location. **Destination**, a subclass of **Location**, describes the OEM location. **IntermediateLocation**, a subclass of **Location**, describes an intermediate location of warehousing the parts between the initial location and destination. Transport class uses two enumeration types: **TransportStage** and **TransportMode** for representing the stage and the mode of transportation. Store is a class that represents warehousing the part. The class uses the enumeration type of **ServiceIndicator** for the type of services that the warehouse provides. Some information classes in this package and in the model, such as location and time and date, will be consistent with information entities defined by the United Nations (UN) Centre for Trade Facilitation and E-business (CEFACT) Core Component Library (CCL) [9, 10]. Energy in the logistics process will be described after the AssemblyProcess package.

Figure 5 is the diagram of the classes in the AssemblyProcess Package. **AssemblyProcess** is the root class in the package. The class represents the actual operation

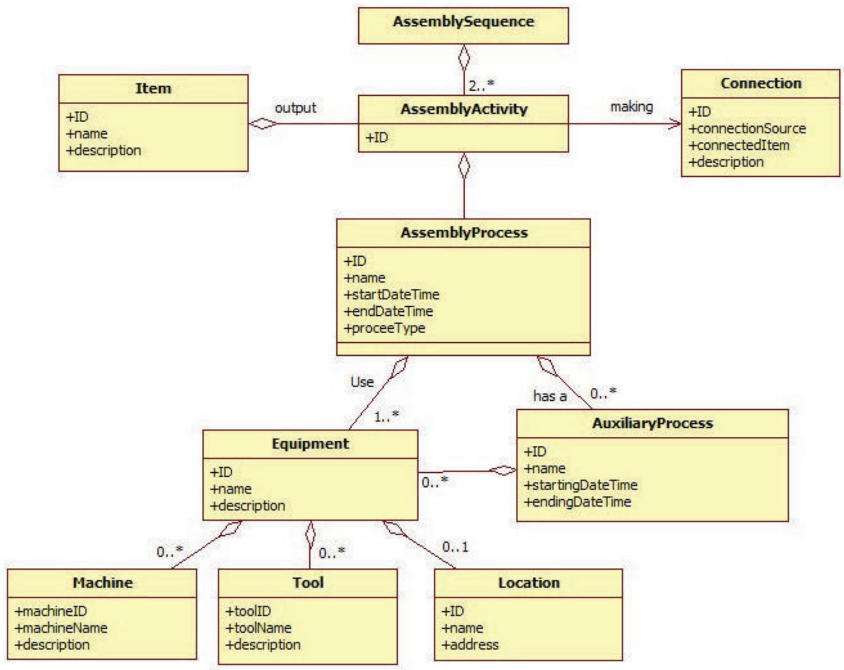

Figure 5. Assembly process package

that connects two or more parts and/or subassemblies by fitting, making contact, or fusion. **AuxiliaryProcess** is a class that represents an auxiliary process that supports the completion of the assembly process but is not directly contributing to the assembly process. **Equipment** is a class that represents equipment that is used in an assembly process or an auxiliary process. **Machine** and **Tool** are the classes representing machines and tools of the equipment. Both assembly process and logistics process requires energy. The energy-related classes for these two components are described next. The energy related classes for supplier (figure 2) are outside the scope of this paper.

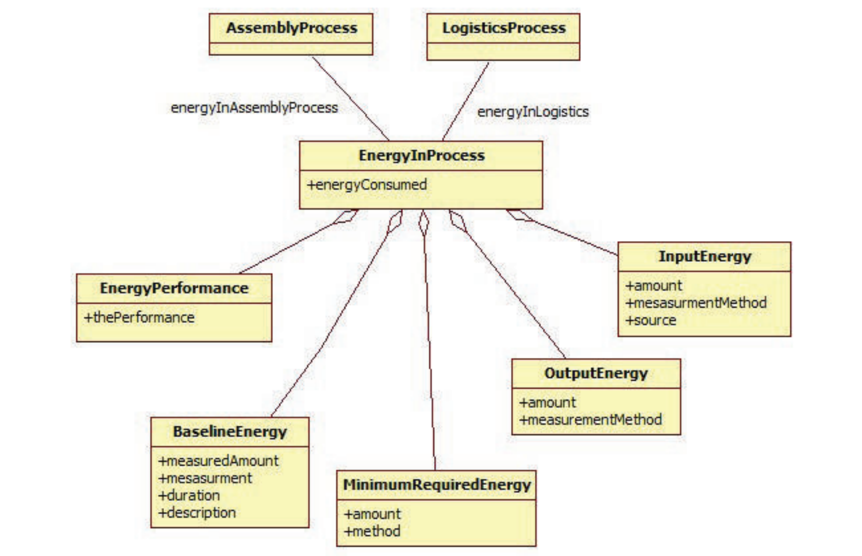

Figure 6. Energy in process package

Figure 6 is the diagram of the EnergyInProcess Package. **EnergyInProcess** is the root class in this package. The class represents energy-related measures for a process and is used by both classes of **AssemblyProcess** and **LogisticsProcess**, described previously. **EnergyInProcess** has attributes of the following classes. **InputEnergy** represents the amount of input energy to a process, such as the assembly process or logistics process. **OutputEnergy** is a class that the amount of output energy from a process, such as the assembly process or logistics process. **MinimumRequiredEnergy** represents the minimum energy required to complete a process. This amount is the theoretical limit and can be used to improve energy efficiency. **BaselineEnergy** represents the historical energy consumption or the industry average energy consumption of a process. Baseline energy is used as the reference for energy improvement. **EnergyPerformance** class represents the energy performance, which is the ratio of the amount of production to a unit amount of energy, of a process. Classes in the EnergyInProcess package provide the capability of evaluating energy performance of a process.

The UML classes comprise the initial information model. The model enable manufacturing companies to share or exchange energy information in assembly processes and logistics activities. The model also provides software developers to develop new tools to evaluate energy performance in assembly and logistics processes.

4 Conclusion

This paper proposes a newly developed information model for representing energy consumption and performance for product assembly processes and logistics activities, including transportation and warehousing. This model provides a formalization of knowledge about the energy performance evaluation in product assembly and logistics. This model also enables integration of energy performance, assembly processes, equipment, and logistics processes. The use of model is expected for sharing information and new software tool development for enabling energy performance evaluation. Future work includes refining the model, and testing, validation, and implementation of the model.

Disclaimer: Certain commercial products may have been identified in this paper. These products were used only for demonstration purposes. This use does not imply approval or endorsement by NIST, nor does it imply that these products are necessarily the best for the purpose.

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