HoVer: A Modeling Framework for Horizontal and Vertical Integration

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***Abstract*—The German working committee for "Industrie 4.0" identified the horizontal integration throughout value networks and the vertical integration of networked manufacturing systems as key issues in the context of smart factories. For this purpose we aim for a universal model-driven industrial engineering framework spanning over production chains and value networks. Thereby, we build up on the Resource Event Agent (REA) business ontology (ISO/IEC 15944-4) to describe external activities requiring horizontal integration with business partners and internal activities serving for vertical integration within a manufacturing enterprise. We plan to apply the ISA-95 industry standard (ANSI/ISA-95; DIN EN 62264) to describe the vertical integration within an enterprise and its decentralized, networked production plants. As a first step, presented in this paper, we extend the REA ontology by useful concepts known from ISA-95 towards an integrating modeling framework.**

I. Introduction

The German working committee for Industrie 4.0[1] has identified among others the following research challenges [1]:

- horizontal integration through value networks
- vertical integration of networked manufacturing systems
- end-to-end digital integration of engineering across the entire value chain

Today, the seamless integration of information flows between the *horizontal layer* (business partner networks) and the *vertical layer* (from enterprise level to shop floor control level and lower) is very limited or not even possible at all. Nowadays, approximately 90 percent of all industrial manufacturing processes are already supported by ICT. The German initiative points to the fact that currently business processes in manufacturing are often still static and implemented through extremely inflexible software systems [1]. An online survey carried out in Upper Austria shows that 41 percent of the interviewed enterprises expect barriers and problems in the implementation of the concept "Industrie 4.0" mainly caused by the diversity of their IT systems. Networking of ICT-supported production systems can be realized on various layers. In order to make this kind of communication work in a universal manner, interfaces between communication units have to be properly configured and functional. It is still common practice that IT systems exchange information through different and often extensive interfaces which were developed over the years. The dependencies between these interfaces are complex and are therefore hard to manage which causes an increase in the complexity. What is missing, in the context of Industrie 4.0, is an all-encompassing architecture supported by an information model enabling an end-to-end information flow from customer requirements over product design to production, marketing and distribution. There is a lack of appropriate concepts for horizontal and vertical integration by which different operational layers can be connected for communication. Furthermore, seamless integration of various stakeholders (e.g., customers, suppliers, employees, business partners, sub-contractors) and their requirements is needed.

Modeling can act as an enabler for managing this integration. *Models* are representations of real and hypothetical scenarios that only include those aspects that are relevant to the issue under consideration. The working group of the German initiative points to the fact that *"the use of models constitutes an important strategy in the digital world and is of central importance in the context of Industrie 4.0"* [1]. For this purpose appropriate language constructs are required to formally describe the increasing functionality, increasing product customization, dynamic delivery requirements, and the rapidly changing forms of cooperation between different companies in order to provide end-to-end transparency.

II. Approach

Industrie 4.0 use case scenarios relating, e.g., to networked manufacturing, customer-integrated engineering, planning and optimization will require *business models* that will primarily be implemented by what could be a highly dynamic network of businesses rather than by a single company (e.g., to link products of a manufacturing company with appropriate services provided by another company) [1]. For realizing a vertical as well as a horizontal integration through value networks appropriate language constructs are needed to describe interface integration within the company between different kinds of IT systems (ERP, MES) at different levels and between multiple enterprises and various participating parties (vendors, sub-contractors, customers).

Accordingly, we aim for a modeling framework that spans over the horizontal and vertical layers. For this purpose we do not intend to start from scratch by defining our own all-encompassing modeling language. In contrary, we want to build up on existing well-accepted modeling languages

[1]Please note, that the approach introduced in this paper is aligned with the German initiative "Industrie 4.0", and therefore, we do not translate it to the English term "Industry".

and align their common concepts to allow for a modeling framework for Horizontal and Vertical integration which we call *HoVer*.

The German working group defines the *vertical integration* as *"the integration of the various IT systems at the different hierarchical levels (e.g., the actuator and sensor, control, production management, manufacturing and execution and corporate planning levels in order to deliver end-to-end solution"*, [1]. We consider the concepts and models of the *industry standard ISA-95* (ANSI/ISA-95; DIN EN 62264) [2], [3] as appropriate to model the vertical integration. ISA-95 is an international standard released by the *International Society of Automation* for developing an automated interface between *Enterprise Resource Planning Systems (ERP)* on the enterprise level and *Manufacturing Excecution Systems (MES)* on the shop floor (control) level. Based upon this standard, which consists of five parts, the norm DIN EN 62264 was established (cf. Section III).

In addition, the German working group defines the *horizontal integration* as referring to *"the integration of the various IT systems used in the different stages of the manufacturing and business planning processes that involve an exchange of materials, energy and information both within a company (e.g. inbound logistics, production, outbound logistics, marketing) and between several different companies (value networks)"*, [1]. Based on our experience, we consider the *Resource-Event-Agent business ontology (REA)* (ISO 15944-4) [4] as a good candidate to describe the required interfaces for horizontal integration. REA is used to identify the value adding activities of a company. In general, value adding activities are either *transformations* by producing something or *transfers* by exchanging something with an external party. In other words, REA is able to provide the binding clue between the internal production processes requiring vertical integration and the external trading activities requiring horizontal integration (cf. Section III). Therefore, we propose to align the concepts of ISA-95 and REA in an integrated modeling framework for vertical and horizontal integration,—HoVer. As a first step, we want to extend the REA ontology by useful concepts known from ISA-95. The inverse direction, the integration and/or transformation of REA concepts to ISA-95 is yet out of scope for this paper, but is an essential future work item.

Following our aim of integrating ISA-95 and REA, we concentrate on these two standards in Section 3 on related work. Section 4 provides the core of our paper. It first introduces the relevant REA meta-models. Then it identifies extensions to these meta-models by integrating ISA-95 concepts. In Section 5, we present an example of a REA model with particular ISA-95 extensions. A summary of our contribution and necessary future work items in the integration of REA and ISA-95 are outlined in Section 6.

III. Related Work

A. Industry Standard ISA-95

The ISA-95 standard has been developed for global manufacturers, i.e., an production company with decentralized, networked production plants. This standard can be applied in all industries, and in all sorts of manufacturing processes like batch processes, continuous processes, and repetitive

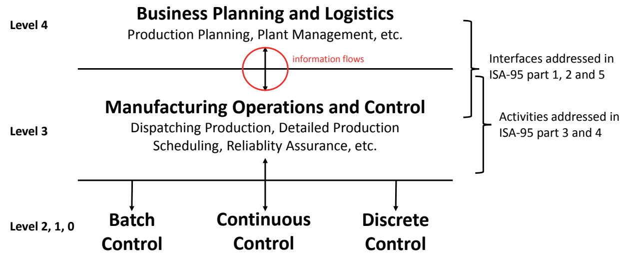

Fig. 1. ISA-95: Functional Hierarchy model [DIN EN 62264-1]

processes. ISA-95 was specifically developed for creating interfaces between the enterprise domain at level 4 and the shop floor control domain at level 3 and lower (levels 2, 1, 0). It offers a fundamental understanding of activities and information flows within a production company (e.g., headquarters and distributed industrial premises). The standard describes hierarchy models which are based on the *Purdue Enterprise Reference Architecture (PERA)* for Computer Integrated Manufacturing (CIM) [5].

Figure 1 shows in a simplified manner the different levels of the *functional hierarchy model*. In addition, the equipment (e.g., site, area, process cell, production line, storage zone) are usually organized in a hierarchical fashion. The red cycle in Figure 1 shows the *enterprise-control interface* between level 4 (ERP) and level 3 (MES). Between these levels the standard points to 31 information flows, as outlined in Figure 2. The wide dotted line of this *functional enterprise control model* illustrates the boundary of the enterprise-control interface. Everything that lies outside the dotted lines belongs to level 4, and everything that lies inside the dotted lines belongs to level 3. The labeled lines indicate the 31 information flows of importance to manufacturing control. The model contains 12 functions. ISA-95 describes point by point the tasks of each of these functions. The functions shown in rectangles (e.g., research, development and engineering, marketing, sales) are external entities and as such are not described in the functional enterprise control model. These entities are components outside the boundaries of this model that send data and receive data from the functions. The basic data to be exchanged in this model are information flows which are defined by ISA-95 for the sectors *personnel, material, equipment/physical asset* and *process segment*. The process segment is a logical group of equipment/physical asset, personnel, material required to carry out a specific part of a process (e.g, mixing, sawing, etc.). These sectors are defined as *object models* in ISA-95 which constitute basic building blocks with which the information flows of the functional hierarchy model are constructed (cf. Figure 1).

B. Resource-Event-Agent Business Ontology

The Resource-Event-Agent business ontology (REA) was developed by William McCarthy [6] for the application-independent description of *economic phenomena* (i.e., exchanges which can either be transfers or transformation of resources). The acronym REA stands for the three main concepts of the ontology *Resource*, *Event*, and *Agent*. Agents are persons, companies, or organizational units capable of having control over resources, who/which participate in an *economic*

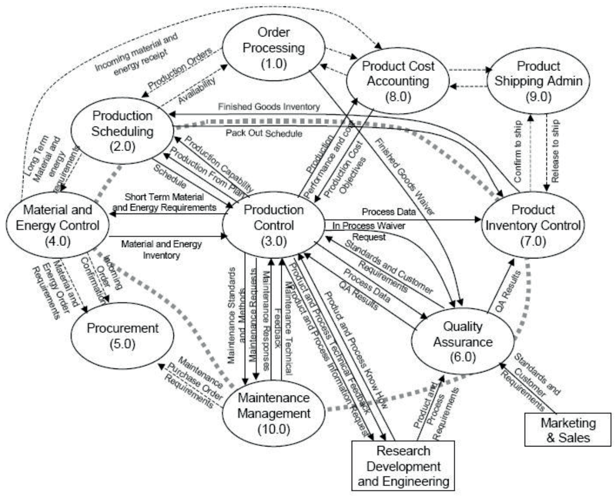

Fig. 2. ISA-95: Functional Enterprise-control model [DIN EN 62264-1]

exchange. Resources are transferred or transformed during an economic exchange. Resources can be goods, material, rights, labor, equipment, physical assets or services which agents have control of and which should be monitored and controlled in a business environment. An event is considered as a class of phenomena reflecting exchanges of resources. REA has its roots in the accounting discipline and is based on strong concepts of the literature in economic theory [7]. Additionally, REA focuses on IT implementation issues and follows a conceptual modeling approach [8]. This makes it a good choice for being used in a business model-driven engineering approach. Moreover, the REA business ontology is a wide accepted language in the academic world to design enterprise information systems. For instance, in the ISO/IEC 15944-4 Open-edi standard [4]—which addresses business communications between enterprises—REA is used as an ontological framework for specifying concepts and relationships involved in business transactions and scenarios. REA initially focuses on concepts of economic exchanges of the present and the past (cf. Section IV-B, Figure 4).

IV. EXTENDING REA BY ISA-95 CONCEPTS

In this section, we elaborate on the extension of the REA ontology by ISA-95 concepts. In our earlier work [9], [10], [11], we have built a formal definition of the REA language concepts by means of Object Management Group's (OMG) meta-modeling architecture called Meta-Object Facility (MOF) [12]. MOF comes with a meta-meta model (M3 layer) that allows us to define the REA concepts as a meta-model (M2 layer). In this section, we first introduce the existing REA concepts by means of meta-models and then show how these meta-models are extended by ISA-95 concepts. REA consists of three different layers concerning entrepreneurial logic and details at a different level of granularity. The three layers from top down are:

1) value chain specification layer
2) duality specification layer
3) task specification layer

In the following two subsections, we explain the meta-models of the first two REA layers. Afterward, we have two subsections that elaborate on extensions of the duality specification layer. In the last subsection, we briefly outline how ISA-95 may be used on the task specification layer.

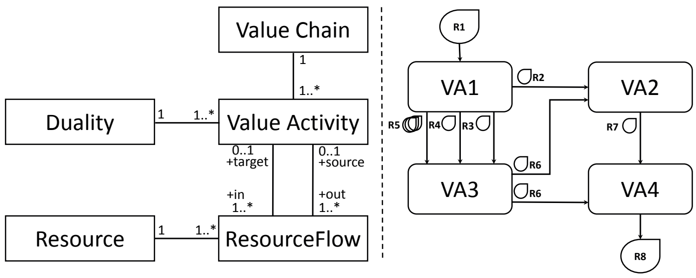

Fig. 3. REA: Value Chain Meta-Model and its Instantiation

A. REA Value Chain

A business model defines how a company creates value. It specifies a competitive strategy by looking at those activties that create value for the company. A seminal work in this respect has been Michael E. Porter's book "Competitive Advantage" [13] in which he first introduces the concept of the value chain. A *value chain* is a set of activities that an organization carries out to create value. Porter proposes the concept of a value chain to examine all of a company's activities, and see how these are connected.

The *REA value chain* is based on Porter's definition. It is built by a number of value activities. A *value activity* takes some resources as input and creates some resources as output. From an economic perspective it is important that the output is considered to be of higher value than the input. On a high level of abstraction there are two ways to create additional value by an activity: firstly, one may use and/or consume some input resources in order to produce some output (e.g., semi-manufactured products, finished goods),—this is called a *transformation* in REA. Secondly, in a trading relationship with external business partners one may receive resources (e.g., material, equipment, transport service, etc.) and give resources (e.g., money) in return,—this is called a *transfer* in REA.

Furthermore, REA is built on the economic principle that any output by one value activity serves as input to another value activity. It follows that it is the resources which connect the different value activities. Thus, a REA value chain contains a number of value activities and specifies the resource flows amongst them—nothing more, nothing else [14]. More details are available on the second layer—the duality specification layer—where we find duality models for each of the value activities (cf. Figure 4).

The left hand side of Figure 3 presents the meta-model of the REA value chain. A value chain includes one to many value activities that are depicted by rectangles with rounded corners (cf. Figure 3 on the right hand side). A value activity is used only once in one distinctive value chain. A value activity points to exactly one duality (described in the next subsection). A *duality* is usually the basis of one value activity, but may be referred to by multiple value activities.

Resource flows tie the value activities together. A resource flow is a directed association that usually starts from a source

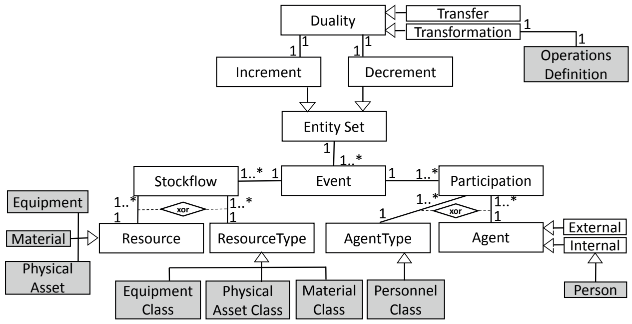

Fig. 4. REA: Duality Meta-Model

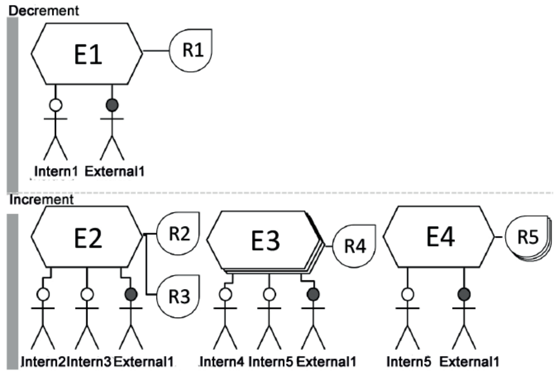

Fig. 5. Duality Example

value activity and ends at a target value activity (cf. Figure 3 on the right hand side). When analyzing a whole company, there is in theory no final output and no input that is not based on an output of another value activity. For the purpose of a partial analysis we permit resource flows that have either no source value activity or no target value activity. It follows that a value activity has at least one, but up to many *outgoing* resource flows. Similarly, a value activity has at least one, but up to many *ingoing* resource flows. Each resource flow points to exactly one resource. This resource is depicted by the sympol of a trop next to the directed arc of the information flow. A resource may be included in many resource flows. The right hand side of Figure 3 shows an abstract example model of a value chain which is a valid instance of the meta-model on the left hand side.

B. REA Duality

In the previous subsection, we learned that value activities receive some input resources to create output recources of higher value. Each value activity is further detailed by a duality on the second REA layer. A *duality* is a core economic principle that says that it is impossible to get something for nothing ("there is no free lunch"). Accordingly, a duality consists of two parts: The *decrement entity set* covers events executed by some agents leading to a decrease of some resources. It is compensated by the *increment entity set* that covers events executed by some agents leading to an increment of some (other) resources. By definition the increment in resources is considered of higher value than the decrement in resources. Again, the duality concept applies to transfers (exchanges with external agents) and transformations (value creation inside the enterprise).

Figure 4 shows the meta-model for a duality. The meta classes with white background describe the existing REA concepts, the ones with gray background represent our proposed extensions described further below. A *duality* has two specializations: a *transfer* and a *transformation*. Independent of the specialization a duality is composed of exactly one *increment entity set* and one *decrement entity set*. Both are specializations of the general entity set. Each entity set is represented in a specific swimlane (cf. Figure 5). According to the REA meta-model, an entity set covers at least one but up to multiple events. An *event*—depicted as a hexagon—is specific to the entity set it belongs to. Following the principles of duality, all events in the decrement entity set (give/consume/use) are counterbalanced by the events in the corresponding increment entity set (take/produce) of the same duality (cf. Figure 4).

The relationship between an event and a resource is described by the concept of *stockflow* [14]. A stockflow is represented as a directed arc between exactly one event (hexagon) and one resource (drop) (cf. Figure 5). In the increment set the direction of the arc goes from the resource to the event, in the decrement set in the reverse direction. An event will affect most of the time one resource only, but it may affect multiple ones. Thus, an event may have one up to many stockflows connected. A resource usually is affected by many different events (in different entity sets of different duality models). At a minimum a resource is affected by one event—otherwise it would not be worth considering the resource at all. Consequently, a resource is connected to one up to many stockflows.

An event involves *agents* depicted as stickfigures. We distinguish between *external agents* (denoted with black heads), e.g., trading partners outside the company, and *internal agents* (denoted with white heads), who are accountable inside the company. The involvement of agents in events is denoted by the concept of *participation*. A participation is an undirected association that connects exactly one event with one agent. An event is associated to at least one, but up to many agents. Hence, an event has one to many participation associations. An agent participates in at least one, but up to many events (in the same, but also in different entity sets of the same or different dualities). Thus, an agent has one to many participations connected. In addition, there are further constraints assigned to the meta-model to handle specifics of transfers. In case of a transfer, each event must be assigned to exactly one outside agent and, in addition, to at least one inside agent [15]. All events of the same transfer (both in the decrement and the increment entity set) must involve one and the same outside agent. Additionally, REA provides concepts for the *typification* of resources and agents [16]. *Resource types* are presented as drops with dotted lines, and *agent types* as dotted-lined stickfigures. It should be noted that due to space limitations, we do not elaborate on the details of event series, resource series and agent series, which are denoted by a staple of hexagons/drops/stickfigures. The interested reader is referred to our paper [9]. Figure 5 shows an abstract example model of the REA concept duality which is a valid instance of the meta-model presented in Figure 4.

C. Extending the REA Resource Concept

In REA, resources can be goods, material, rights, labor, equipment, physical assets, or services. REA does not make any particular differentiation and all of these resources are denoted by the icon of a drop. Due to its dedicated focus on the production domain, ISA-95 differentiates between *material*, *equipment*, and *physical asset* as special kinds of resources. When aiming for an integrated approach the differentiation of these special resources should be reflected in the REA ontology as well. Accordingly, we define material, equipment, and physical asset as specializations of the REA resource (see classes with grey background in Figure 4). In addition, we define specializations for the corresponding typification concepts, i.e. material class, equipment class, physical asset class are defined as specializations of the REA resource type. We also define dedicated icons for them. A material is denoted by a cuboid, an equipment by a white gear wheel, and a physical asset by a black gear wheel. All of these specializations may also be used whenever a resource is expected in REA, i.e., as part of a duality and as classifiers assigned to resource flows.

ISA-95 defines corresponding models for these specializations [3]. The *material model* defines the actual materials, material definitions, and information about classes of material definitions. Material information includes the inventory of raw, finished, intermediate materials, and consumables. The information about planned or actual materials is contained in the material lot and material sublot classes. The material model organizes information for manufacturing operations definition, scheduling, capability and performance [3]. The role-based *equipment model* contains information about specific equipment, the equipment class, their particular properties, and an equipment capability test. This test ensures that the equipment has the necessary capability and capacity. Role-based means that the equipment model is used to construct hierarchy models used in manufacturing scenarios (enterprise, site, area, work center, work units, process cells, etc). Due to this role-based view the equipment model is related to the *physical asset model* [3]. This model contains information about the physical piece within the manufacturing enterprise, i.e., a specific equipment.

D. Extending the REA Agent Concept

Another REA core concept are *agents* (cf. Section IV-B). In particular, REA differentiates between external and internal agents (cf. Figure 4). In addition, agent types provide a means for the typification of agents. As outlined below, ISA-95 provides similar concepts called *person*—which refers to particular persons internal to the company—and *personnel* as a kind of typification of persons. Accordingly, the ISA-95 classes become specialization of internal agent and agent type, respectively.

The *personnel model* contains information about specific personnel (class Person), classes of personnel (class Personnel Class)—as well as their properties—, and qualifications of personnel. The *qualification test specification* in the personnel model includes information about the representation of a qualification test. This concept is typically used where a qualification test is required to ensure that the person class or a person has the correct training and/or experience for specific operations for a specific process segment [3].

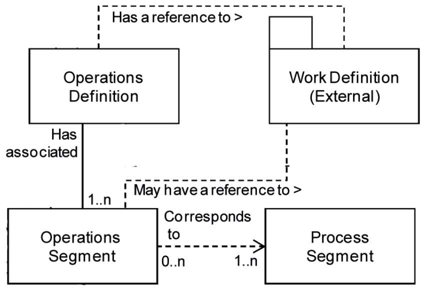

Fig. 6. ISA-95: Part of the Operations Definition Model [DIN EN 62264-2]

E. Extending the REA Task Specification Layer

In the first two subsections, we elaborated on the top two layers of REA (value chain specification layer and duality specification layer). One may expect that we do the same for the third layer—the *task specification layer*—describing the process to transform the input to the output as defined in the layers above. However, the REA literature does not concentrate on the task layer, because it is said to be domain specific. Consequently, REA does neither provide any language concepts for the task specification layer nor does it mandate a specific language to be used on this layer. In the context of the production domain, we are confident that ISA-95 is a perfect candidate to be used on the task specification layer. Accordingly, we propose that each REA duality model points to exactly one ISA-95 operations definition model. The corresponding meta-model association is shown in the upper right of Figure 4.

Figure 6 shows the ISA-95 classes that serve as the entry points to specify the task specification layer by means of ISA-95. The *operations definition model* defines the resources required to perform a specific operation [3]. The *operations definition* is applied to defining production, maintenance, quality test and inventory operations. The information needed to quantify a segment for a specific operation is presented by an *operation segment*. It identifies references or corresponds to a process segment. A *process segment* is a logical grouping of personnel, equipment, physical asset, material and the quantity (e.g., the time duration associated with a resource) of these resources required to perform a specific manufacturing operation step. The process segment is the smallest element of a manufacturing activity (e.g., sawing). The *work definition* defines how to perform a manufacturing operation.

V. Example of the Extensions

The business model of Maxi Bike is to produce and sell bicycles. Figure 7 presents Maxi Bike's value chain. Keeping the example simple and easy to follow, we only present a partial analysis and do not show value activities for acquiring equipment, physical assets, raw materials and labor. The *value chain* covers five *value activities*: `Purchase`, `Transport`, and `Sale` are REA-transfers requiring horizontal integration, whereas `Production` and `Assembly` are REA-transformations requiring vertical integration. The value chain shows the flow of resources (materials/equipments/physical assets) amongst them. In `Purchase` the *resource* `cash` is used to get the *material* `wheel`. The `wheels` and again `cash` are used in `Transport` to receive the `wheels` at

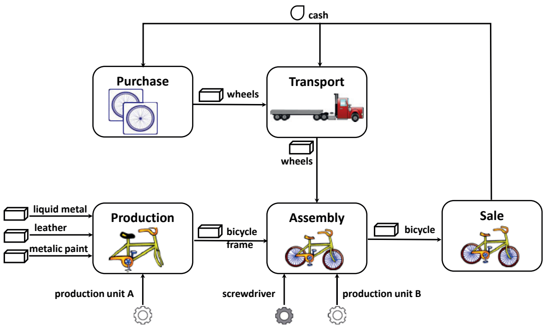

Fig. 7. Bycicle Production - Value Chain

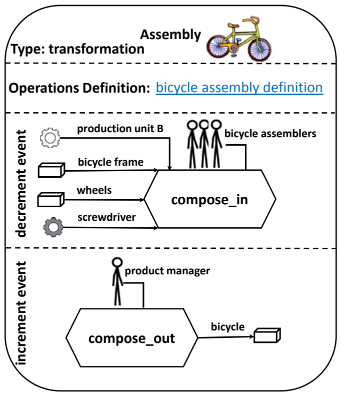

Fig. 8. Assembly - Duality Model

the right location. In `Production` the *materials* `liquid metal`, `leather`, and `metalic paint` are transformed to the *material* `bicycle frame` by the use of the *equipment* `production unit A`. The `Assembly` uses the *physical asset* `screwdriver` in `production unit B` to assemble the `bicycle frame` and the `wheels` to create the `bicycle`. In the *value activity* `Sale` the `bicycle` is turned into `cash` which is used as input for the other *value activities*.

Each of the five *value activities* in Figure 7 must be refined by a *duality* model. Due to space limitations we only show the *duality model* for `Assembly` (cf. Figure 8). `Assembly` is of the REA type *transformation*. The `compose_in` *event* is performed by the *agents* `bicycle assemblers` and leads to a decrease of the input resources by consuming the *materials* `bicycle frame` and `wheels` and using the *physical asset* `screwdriver` in the equipment `prodcution unit B`. This *decrement event* is compensated by the *increment event* `compose_out`, which produces the *material* `bicycle` as final product received by the *agent* `product manager`. This example model does not specify any process details on how to assemble the bicycle. It only provides a link to the *operations definition* `bicycle assembly definition`, which associates the corresponding *operations segments*, *process segments* and *work definition* (cf. Figure 6).

VI. Conclusion

It is our overall goal to develop a universal model-driven approach towards the horizontal and vertical integration in the context of smart factories. For this purpose we strive for an integrated modeling framework (HoVer) based on existing modeling approaches. Thereby, we built up on the REA business ontology to identify, both, activities requiring *horizontal integration* with business partners and activities serving as hooks into the internal systems requiring *vertical integration*. The latter activities have then to be further detailed by means of the ISA-95 standard. Accordingly, it is of crucial importance to align the concepts of REA and ISA-95. In this paper, we have provided a first step in this direction by extending the REA core concepts *resource* and *agent*. Furthermore, we integrate ISA-95 as the language of choice for the *REA task specification layer*. For evaluation, we implemented the REA extensions into our REA-DSL tool to demonstrate the technical feasibility. In future work, we plan to (i) go the reverse direction by providing REA hooks into ISA-95, (ii) specify transformations between ISA-95 and REA, and (iii) provide the data exchange mechanisms between the horizontal and vertical layers.

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