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EXTENDING ERP WITH RECIPE AND MATERIAL TRACEABILITY

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Abstract

In this paper recipe and material traceability are modelled for ERP. The paper describes how a given Enterprise Resource Planning (ERP) reference data model from science, is supplemented with desired functionality to perform tracking and tracing. The paper discusses thereto the essentials of production data modelling and the modelling of requirements for tracking and tracing. Successively obtained, are two part-models: one ERP production data model and one tracking and tracing data model. In the paper, the functional integration of both models is described. Obtained is a general modelling solution for recipe and material traceability in manufacture.

Keywords: Tracking and tracing, recipe, reference data model

Introduction

Tracking and tracing represents in a formal way and in accordance with stakeholder and integrity requirements, historic information on properties of objects in the object system. Descriptions of tracking and tracing can be found in literature (Töyrylä, 1999; Eads and Undhein, 1984; Steele, 1995; Kim et al., 1995; MESA, 1997). In this paper, reference data models for tracking and tracing are described. These models record the knowledge and experience of tracking and tracing in enterprises.

While a regular data model represents a specific enterprise solution, a reference data model represents a solution of a class of systems, i.e. a general solution. Reference models represent a higher system abstraction than regular models. A regular model is of value to a specific situation while a reference model is of value to a general situation. A reference model is generic of nature and can be customised to fit a specific enterprise situation. From standpoint of ERP, reference data models are a particular valuable asset, they change the nature of enterprise modelling from a one-of-a-kind activity into a modify-the-template activity (Wortmann, 1998).

The objective of the paper is to describe the extension of an ERP reference data model, with tracking and tracing functionality. No vendor-specific solution is suggested: a scientific modelling solution is proposed. A functional integration of two reference models is presented. A scientific ERP reference model is taken as the basis.[1] This reference model is described in literature (de Heij, 1996). Another model, a tracking and tracing reference model, is used for the extension. The tracking and tracing model is also described in literature (Dorp van, 2002). The model-integration of both solutions is presented in the paper.

The paper first discusses the modelling of production functionality (without functionality to track and trace). Following, the modelling of tracking and tracing functionality is discussed. Concluding, the functional integration of both part-models is presented, to obtain one general reference modelling solution for tracking and tracing in manufacture.

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[1]The reference model was primarily developed by combining a large number of data structures from renowned packages.

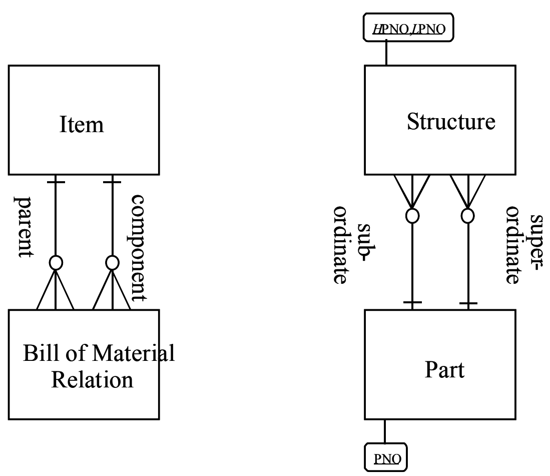
Modelling Production Functionality

In this section, reference models are described that make up the heart of contemporary enterprise systems. The reference models include entity types that cover the recording of materials, operations, capacities, routings and recipes. These reference models can be considered the primary point-of-departure for introducing reference data models for tracking and tracing. Next, it is illustrated what these reference models look like and is explained what purpose they serve. Reference models for material requirements (bill-of-material) and capacity requirements (routing or bill-of-operations) are presented in the first sub-section. Reference models supporting multiple bill-of-materials, routings and recipes, are presented in the second sub-section.

Material and Capacity Requirements

In order to produce an item, material and capacity requirements will have to be established by the enterprise. An item is considered any unique manufactured or purchased part, material, intermediate, subassembly, or product (APICS, 1998). The traditional way of recording material requirements for the production of an item is the bill-of-material. A bill-of-material is a listing of all the subassemblies, intermediates, parts and raw materials that go into a parent assembly, showing the quantity of each required, to make an assembly (APICS, 1998). In (semi-) process industries one refers to recipes and formulae. These are defined broader than the traditional bill of material.

In the parent-component relationship all the required component items are determined including the required quantity for the production of the parent item. As a component item itself can be a parent item, a multi-level structure can explode until the component items no longer are manufacturing items but purchase items. Figure 1 presents two different representations of a bill-of-material, containing material requirements. In customer order controlled production it often occurs that a component is not known beforehand, in the data structure this means that the component relationship type is optional. The higher-order (super-ordinate) and lower-order (sub-ordinate) dependency relations of the bill-of-material determine what components are required and how these components are applied in the construction of a certain end product. In the bill-of-material a component can be assigned to multiple higher-order (super-ordinate or parent) components: this is what is referred to as communality of the component. In principle, it is not allowed for a component to (indirectly) be a component of itself: a never-ending cycle (loop) would arise in the execution of a bill.



(A) Bill-of-materials
(*Source*: adapted from de Heij, 1996, p. 170)

(B) Bill-of-materials and its keys
(*Source*: adapted from Scheer, 1998, p. 101)

Figure 1. Multi-Level Bill of Material

Besides material requirements, the production of an item is also determined by capacity requirements. Capacity requirements denote the machine capacity of a component operation in producing a certain item (Bertrand et. al., 1990). An operation is a job or task, consisting of one or more work elements, usually done essentially in one location (APICS, 1998). The description of an operation is normally contained in a routing document, and can include set-up instructions, operating instructions (feeds, speeds, heats, pressure, etc.) and required product specifications or tolerances (APICS, 1998). A routing is a set of information detailing the method of manufacture of a particular item, it includes the operations to be performed, their sequence, the various work centres involved and the standards for set-up and run (APICS, 1998).

Figure 2 depicts a simple reference model for the production planning of an item. It represents the routing (i.e. bill-of-operations), the required capacity and the available capacity (on the calendar). The material requirements represented by figure 1 and the capacity requirements represented by figure 2 can jointly be represented by figure 3. Figure 3 represents the basic material and capacity requirements many contemporary enterprise systems incorporate.

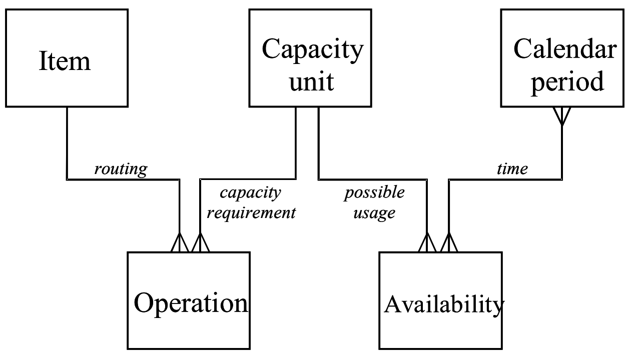


Figure 2. Capacity Requirements (de Heij, 1996)

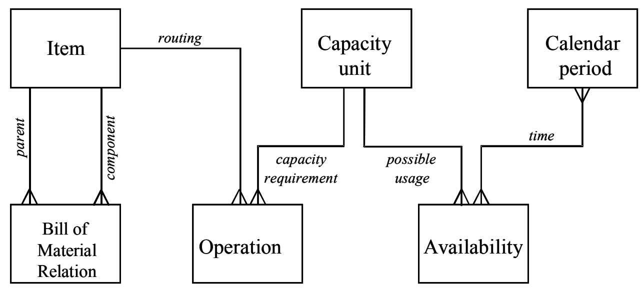


Figure 3. Combined Requirements (de Heij, 1996)

As can be concluded from figure 3, no relation exists between the material requirements and the actual operations on capacity units. This de-coupling however is not always desirable as no information is (then) at hand as to where and when materials are actually required during production. In lengthy processes, this may lead to too early ordering and/or reservation of valuable materials, which may induce a more rigid production planning. The problem can be avoided by relating the bill-of-material relations entity type with the operation entity type via a material requirement (*consume*) relation. This material requirement relation then specifies at which (normative) operation a specific component is consumed for assembly of a parent. Figure 4 depicts the new relation.

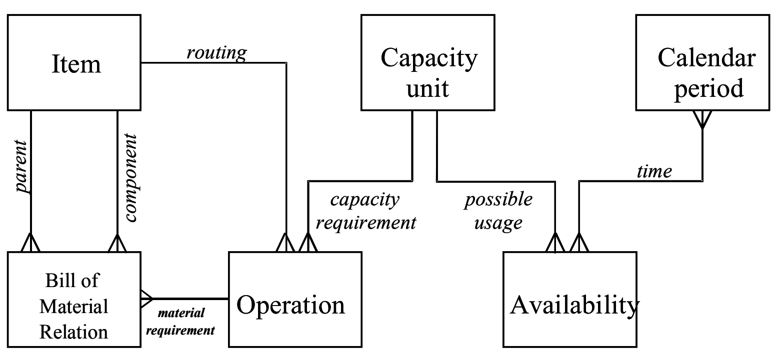


Figure 4. Material Requirement (Consume) Relationship (de Heij, 1996)

The models depicted in this section have been relatively simple, in the sense that little flexibility is offered. For example, no selection is possible between different bill-of-materials and/or routings, nor is there functional support for recipes. Satisfying the requirements of the discrete, semi-process and process industry however, generally requires more complex functionality. The requirements of these industries are discussed next in more detail. The support for multiple bill-of-materials, routings and recipes will be elaborated on.

Multiple Bill-of-Materials, Routings and Recipes

The functionality described in the previous section is straightforward. In many situations such functionality does not suffice for proper functioning of enterprise systems. Then, more complex functional requirements are to be incorporated such as the support of multiple bill-of-materials, routings and recipes. The support of multiple bill-of-materials and routings may derive from a number of factors (de Heij, 1996). Distinct disciplines such as engineering may require different types of bill-of-materials. After all, engineering would like to review bill-of-materials with different components and different structures, bill-of-materials that are probably different from the bill-of-material of production. Also, on shortage of components one would like to use an alternative bill-of-material for the production of the same item. Further, the application of temporary bill-of-materials might be required for the reprocessing of particular items (rejected materials, returned items, etc.) Further, product and process improvements may induce revised bill-of-materials and routings. Such improvements may require multiple bill-of-materials and routings to be available in transition of one situation to another. Finally, on managing more than one production site, location dependent bill of materials and routings can be required. Local differences can exist in the capacity units present and/or the use of components due to local differences in component price and/or quality. The support for multiple bill-of-materials and routings requires that the reference model figure 3 is extended with entities that allow a choice in routing and bill-of-material. This revised reference model is depicted in figure 5.

The entity type 'bill-of-material' allows for the selection of alternative bill-of-materials for the production of a certain item. Similar, by introducing the entity type 'routing', alternative routings can be chosen from along which an item is produced. Explained with figure 4 was the material requirement or consume relation between the bill-of-material-relation and the operation entities. The relation depicted, at which operation a component is consumed for the assembly of a parent. Given that figure 5 includes multiple routings, a material requirement for the production of a certain parent item may also apply at operations of alternative routings. Hence, in figure 5 the material requirement relation is transformed into a n:m relation between the entities 'bill of material relation' and 'operation'. Also, when additional capacity requirements such as personnel requirements or other requirements must be established for an operation, then the singular relation of figure 4, between the 'operation' entity and the 'capacity unit' entity (also) no longer suffices. Figure 5 creates the n:m relation between these entity types with the introduction of entity type 'operation capacity requirement'.

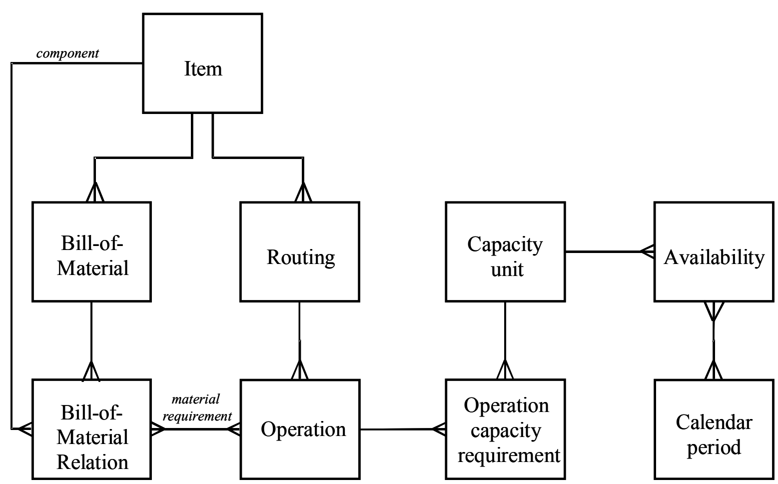


Figure 5. Multiple Bill of Materials and Routings (de Heij, 1996)

The reference model now obtained and depicted in figure 5 would generally suffice the ***discrete*** industry. The semi-process industry however, often has more specific requirements compared to those posed by the discrete industry. The cause for this is the nature of the production process. The ***semi-process*** industry has a number of specific characteristics (van Rijn et al., 1993). Some characteristics are: ranging materials quantity, different material and capacity options and process flexibility:

- The exact quantity of materials used in production may vary between boundaries. Material consumption may deviate from the ones planned. Hence, variable yield may occur due to variations in production.

- Specific options are often possible when deciding about the installations to use in production or when deciding about what materials to use.

- In certain cases the output of an intermediate process may determine which operation to perform next. This requires output-driven process-execution and a flexibility that is not planned top-down. Actions depend on the evolution of the product to be accomplished.

What becomes clear from the description of the characteristics of the semi-process industry is that different recipes (each with a specific capacity and material requirement) can co-exist for the production of one particular item. For the production of a certain food item for example, a summer and winter recipe may exist (de Heij, 1996). Several recipes for the production of one item can (co-)exist. Consequently, enterprise systems for the semi-process industry should include flexibility for material and capacity requirements.

Moreover, in ***process-oriented*** industries it even occurs that the material structure is *very* simply, thereby applicable or identical for a large number of finished products. Then, on generating a finished product, two distinctions will then have to be made:

- the variety of finished products is determined by the production process
- the variety of products is determined by the materials or ingredients

Considering the first option, finished products are not differentiated because of the use of different materials, but the operations performed on the materials make the difference. Hence, the first option describes standard materials with which different products can be produced depending on the process executed. The second option, i.e. the reverse of the first option, differentiates products on ingredients while maintaining operations. Hence, the second option describes a standard process with which different products can be produced depending on the ingredients. Clearly, for the standard practices in the process industry it is desirable to be able to define the material and process structures independently of the item to be produced and be able to combine them into an item-specific recipe. Three types of standard data may be distinguished, independent from the item to be produced:

- standard bill of material: records the material structure independent of the item to be produced
- standard routings: records the process structure independent of the item to be produced
- standard operations: records the operation as standard and independent from where it is released on

Concluding, in addition to bill-of-materials and routings: recipes are important to reference modelling. A recipe or formula is a statement of ingredient requirements, which may also include processing instructions and ingredient sequencing directions (APICS, 1998). A recipe describes all that is necessary for the production of an item, i.e. the combination of required materials, capacities, additives and instructions (de Heij, 1996). In order to be able to effectively deal with the material and capacity requirements of the (semi-) process industry, the reference model of figure 5 is synthesised with the recipe entity type. The model now obtained, is depicted in figure 6. This model is the functional basis for the extension with tracking and tracing. Upcoming sections elaborate on the tracking and tracing model, with which *this* reference model will be extended.

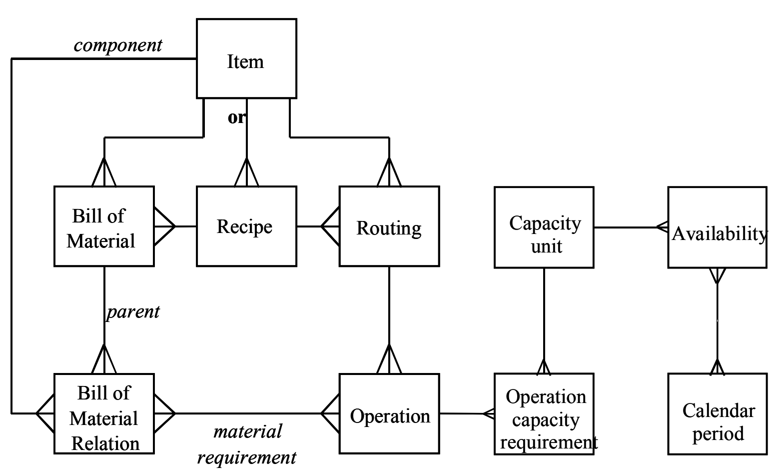


Figure 6. The Synthesis with Recipes (de Heij, 1996)

Modelling Tracking and Tracing Functionality

In preceding sections, contemporary enterprise system functionality for manufacturing was described. The basic functionality described, included: material and capacity requirements and multiple bill-of-materials, routings and recipes. The functionality incorporated by the model of figure 6 does provide a good means for manufacturing *planning*. It however does not provide sufficient functionality to perform *tracking and tracing* in manufacturing.

To be able to perform tracking and tracing in manufacturing, the requirements that are represented by the current model do not suffice. In particular, the data model does not support the registration of material or batch relations, nor does it address the consumption of lots and batches in production. For that matter, no registration of data on actual operations is foreseen at all in the current reference data model of manufacturing. Nevertheless, it is desirable to trace lots and batches through production and moreover, register actual operations on lots and batches along with operation variables and associated values. Moreover under contemporary legislation, it is desirable to keep materials' history and the operating data, traceable, under each production order that is executed. It is therefore very much evident, that the manufacturing reference model should be extended with functionality for tracking and tracing.

A reference modelling solution for tracking and tracing must be able to support the registration of historic relations between lots and/or batches, support the registration of operations on lots and/or batches in production and, support the registration of associated variables and values, on operation (Dorp van, 2002). Next is discussed how these requirements can be represented by a reference modelling solution. Important part-models of such solution are elaborated on. First, the modelling of the bill of lots (batches) is discussed. Second the modelling of actual operations and associated variables are elaborated on. Third, the modelling of the *coupling* of the bill of lots and actual operations is described.

Bill of Lots (Batches)

According to tracking and tracing requirements, manufacturing should be able to register which lots made a contribution to the composition of a certain end product batch. Lots consumed in production must be tracked through the production process in order to be able to determine the composition of the end product down to its constituent parts. It is therefore necessary that each parent assembly maintains traceability relations with its sub-assemblies. By registering the relations between sub-ordinate and super-ordinate material lots, a method of tracking the composition of the end item is obtained. When the entire sequence of activities required for manufacturing of a certain end item, adheres to this registering of relations, a multilevel bill of lots can be compiled. That bill of lots then contains the necessary data to determine, (1) the composition of an end product out of component lots (backward traceability) and (2), all end products having consumed a component lot of specific interest (forward traceability).

Understanding the design of the bill of lots requires knowledge of the design of the bill of materials. The bill of materials is known to register each relation between a sub-ordinate entity and super-ordinate entity. It comprises of a list of components required for the production of a parent item. From a designers view, the bill of materials represents a set of parent-component relationships whereby each relationship is an entity in itself (Scheer, 1998; Bertrand et al., 1990). The relationship is characterised by such attributes as: parent item identification, component item identification, effective start date (the date the relation is activated), effective end date (the date the relation is de-activated), quantity of component, yield/scrap factor (the ratio of usable output from a process to its input), etc. A designers' representation of the bill of material was depicted in figure 1. The figure displayed the data structure of the multi-level bill of material.

The bill of lots is designed analogous to the bill of materials (Dorp van, 2001a; Dorp van, 2001b). The bill of lots consists of two entity types (lot and relation) and two relationship types (explode and implode). The lot entity stores the unique identification and associated data attributes of a lot. Item identification, description, unit of measure, original quantity, remaining quantity and order type, are examples of lot entity attributes. The relation entity stores the unique identification and associated data-attributes of a relation. Actual start date (the date the relation is actually activated), actual quantity of consumed material and actual yield/scrap factor, are examples of relation entity attributes. For the relation entity holds: the combination of sub-ordinate and super-ordinate lot identification is unique. The relationship types explode and implode, are used to explore where-from and where-used relations. Figure 7 depicts the bill of lots.[2]

[2]With more cardinal expression than the given reference models from science (depicted previously).

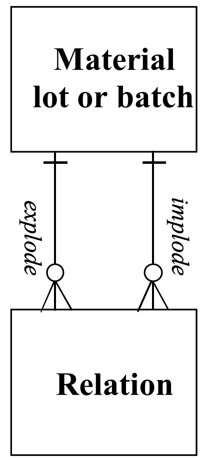


Figure 7. Bill of Lots

Actual Operations and Variables

A manufacturing process is a network of manufacturing steps, which have been aggregated into operations for the purpose of manufacturing control (Bertrand et al., 1990). In manufacturing planning, items are prescribed so-called normative operations on capacity units. In production execution however, tracking and tracing requirements demand specific data on actual operations performed, and not on normative operations. Hence, actual operations must be linked to the production order execution of a certain item. The reference data structure to realise this is depicted in figure 8. Furthermore, from production point of view an operation is a black box with specific properties, which are not subject to internal manipulation (Bertrand et al., 1990). The transformation of materials during an operation is performed under certain constraints with specific operating instructions. Nevertheless, deviating material input specifications and operating conditions, can be cause for deviation of the materials output specification. With the input deviation known however and the operating conditions registered, output deviation can be established within certain boundaries. Therefore, read-out of operating variables is important from viewpoint of tracking and tracing. Hence, it should be possible to link the actual values of operation variables to the actual operations executed. This functionality also is depicted in figure 8. Further, the actual operation executed, should be related to the actual capacity unit on which the operation is performed. This functionality is represented by figure 9.

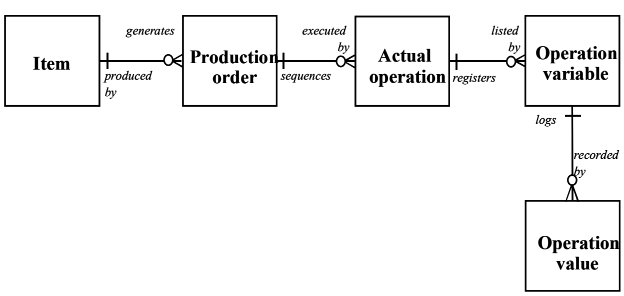


Figure 8. Operation Performance

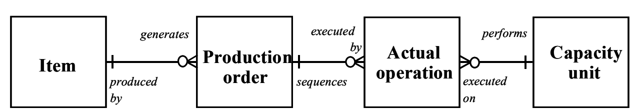


Figure 9. Capacity Unit of Operation

Coupling of the Bill of Lots and Actual Operations

In general, customer-items are obtained by generating one or more manufacturing orders, each issuing a particular material lot. The final material lot is obtained through a sequence of multiple (actual) operations in manufacturing. The list of actual operations should be kept traceable in relation to the final production lot. This, however, was not included in the data models presented previously. The functionality can be included, by relating the material lot entity type to the actual operation entity type. This functionality is depicted by figure 10. Further, relations between sub-ordinate and super-ordinate lots are formed on actual operations. In the discussion thus far however, the recording of data on lot relations and the recording of data on operations have been treated as two separate things. Such de-coupling however is not desirable as it prevents us from mapping the actual operating data on the relations recorded in the bill of lots. Operating data and relations in the multilevel bill of lots must be related on the right level. Clearly, operating data should not be registered on the level of the production order (the final production lot), as then data on operations are aggregated over all the (multilevel) relations and it will be impossible to narrow down a particular problem. Therefore, traceability relations must be stored in conjunction with the operation[3] that invoked them. This can be included in the data model by adding a material requirement relationship between the actual operation entity type and the relation entity type (figure 11).

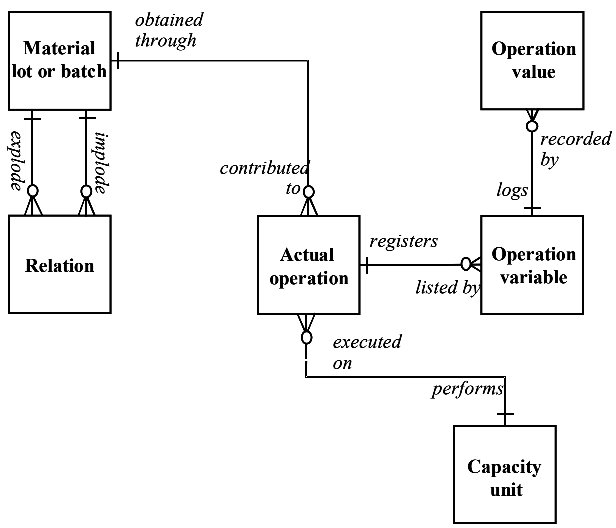


Figure 10. Operations Sequenced

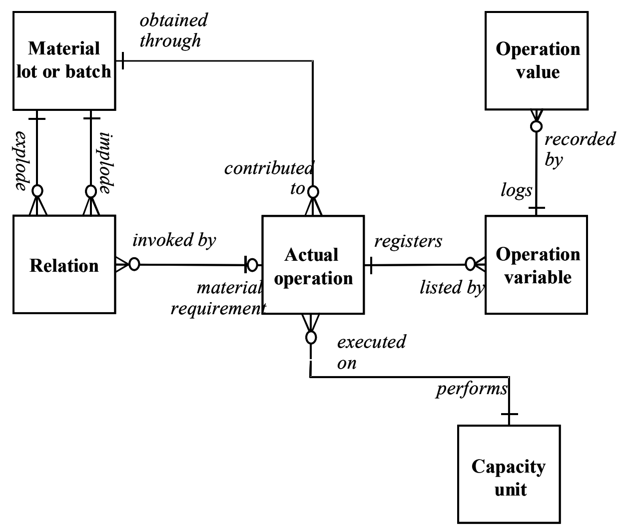


Figure 11. Operations with Their Material Relations

The integrated reference model is designed to accommodate support for the registration of historic relations between lots and/or batches, support for the registration of operations on lots and/or batches and support for the registration of associated operation variables and values (figure 12). The model derived here, includes the relevant data entity types and relationship types concerning the item produced, the production order responsible, the material lot obtained, the history on constituent material parts, the data of processing and the capacity units processed on.

Integration of the Two Model-Solutions

The integration of existing enterprise functionality with the required functionality for tracking and tracing in the domain of manufacturing, is depicted by the reference data model of figure 13. Similar entity types occurring in both part-models were replaced by one entity type in the integration, as to avoid functional *inconsistency and redundancy* from occurring. The obtained model incorporates the essential functional requirements noted on tracking and tracing for manufacturing. With the functionality, manufacturing can trace the actual sequence of activities of transforming a listing of raw materials, parts, intermediates and subassemblies into one particular end product batch. More specific, manufacturing can determine the composition of each end-material lot produced, down to its constituent parts, view the material consumption of operations and trace any material of specific interest throughout production. The core functionality for all these possibilities is the bill of lots, which is based on a design analogy of the bill of material. Next, the functionality of the integrated model is discussed.

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[3]Read: converging operation.

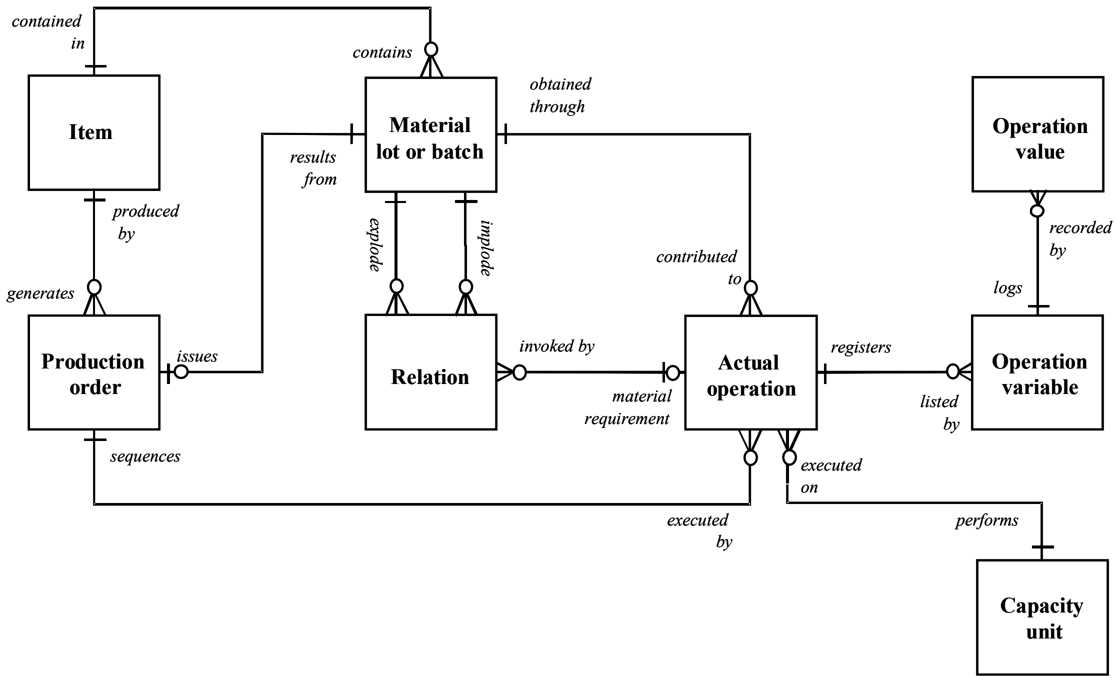

Figure 12. Tracking and Tracing Model

The model displays the production of an item through the execution of a production order. The production order issues a material lot/batch containing the production item. The material components used in the production of the item, are recorded in the bill of lots/batches. As a result, all material components remain traceable under the production order, as these are related to the final material lot/batch of the item. Further, all operations sequenced under the production order, can be traced. Moreover, their material consumption is registered, as are their generated output batches. Further, the performance of each operation can be assessed in detail, because of the recording of operation variables and values.

The production order can be considered an important entity type. The production order can be regarded the linking pin between the state independent part and the state dependent part of the reference model. The state independent part of the model records all *normative* bill-of-materials, routings and recipes, while the state dependent part of the model records all *actual* bill-of-materials, routings and recipes. As the model includes both normative and actual recordings of production, any production *change*, can be traced.

Conclusion

In this paper the extension of ERP with recipe and material traceability was described. The paper showed how an Enterprise Resource Planning (ERP) reference data model was supplemented with desired functionality to perform tracking and tracing. First, essential functionality of contemporary ERP systems was discussed. Reference data models described the recording of materials, operations, capacities, routings and recipes.

Second, essential functionality of tracking and tracing was discussed. Reference data models described the recording of historic relations between lots and/or batches, actual operations on lots and/or batches, and associated variables and values of operations. Two part-models were then obtained: one ERP production data model and one tracking and tracing data model. Both part-models were functionally integrated in a way that inconsistency and redundancy were avoided. Obtained is a general reference data model for tracking and tracing in manufacture.

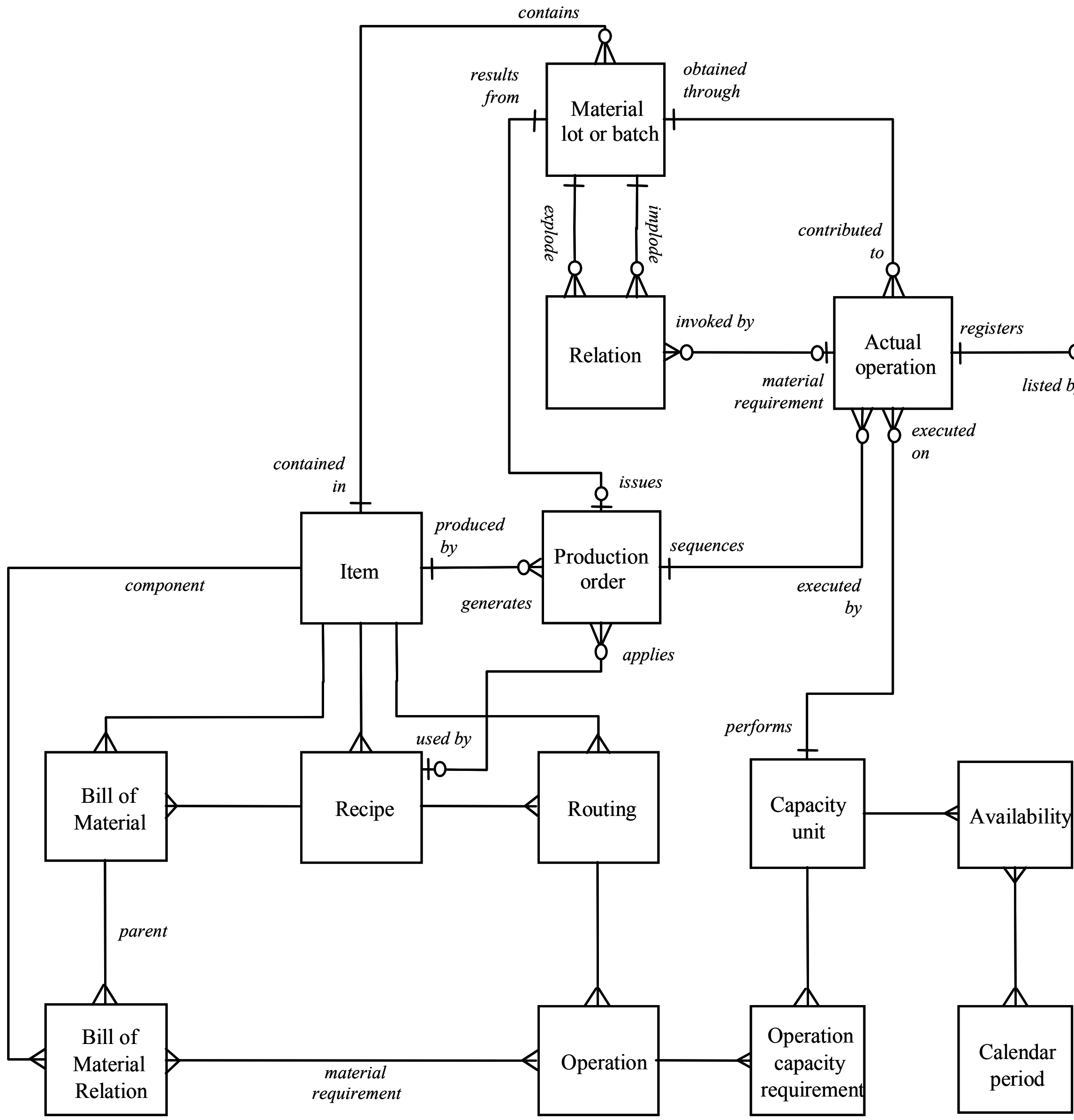

Figure 13. Extended Manufacturing Reference Data Model

A pragmatic delimitation was made with respect to the inclusion of functionality for production and traceability. The requirements modelling for production and tracking and tracing should therefore by no means be interpreted as exhaustive. Also, it is not excluded that alternative modelling solutions are possible, next to the models presented in this paper. The obtained modelling solution of this paper then, should not be interpreted as a one-of-a-kind solution.

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