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Abstract

Manufacturing companies often have difficulties developing production platforms, partly due to the complexity of many production systems and difficulty determining which processes constitute a platform. Understanding production processes is an important step to identifying candidate processes for a production platform based on existing production systems. Reviewing a number of existing classifications and taxonomies, a consolidated classification scheme for processes in production of discrete products has been outlined. The classification scheme helps ensure consistency during mapping of existing production systems, and assists in providing an overview of when, where and how fundamental functions of a production system are realised.

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Keywords: processes, production, manufacturing, handling, classification, ontology, taxonomy

1. Introduction

Research into platforms standardising assets in production (i.e. production platforms) is gaining traction as a way to map products with corresponding production systems and developing both simultaneously [1,2]. Development of these production platforms remains a difficult task. One aspect of this lies in identifying what should be part of a platform and what should not [3]. An important step in platform development is being able to understand and consistently identify common processes, elements and interactions across multiple complex systems. For identification of candidate processes across production systems, a classification of production processes can prove beneficial.

A number of taxonomies exist for both manufacturing, handling, test and control processes, each with their own basis for differentiation, as covered in greater detail in Section 3. None of the classifications or taxonomies uncovered during this study have incorporated both material handling and manufacturing processes in the same classification, while a few have included test and inspection processes [4,5].

The production platform development task could greatly benefit from a consolidated classification scheme incorporating manufacturing, handling, control and inspection processes in a consistent and coherent manner. This could ease the process of mapping production systems, and potentially facilitate the use of optimization approaches in comparing production systems and identification of candidate processes for production platforms. For the iteration of the classification scheme presented in this study, the focus has been on outlining the overall structure and subsequently classifying manufacturing and handling processes being carried out during production. Thus, the classification scheme is still a work-in-progress, with several branches still needing to be fleshed out. To frame this paper, the following research question has been formulated:

- How can processes during production of discrete products be classified independently of the means facilitating the process?

It is likely that the classification scheme and several of the included processes are applicable outside the production of discrete products (i.e. the process industry), but the focus of this study has been discrete products. Creating a classification scheme for the process industry may pose different challenges to discrete production due to a preponderance of essentially shapeless materials.

This paper firstly presents the employed method for creating the classification scheme, and an overview of classifications and taxonomies used in this process, followed by a presentation of the overall scheme and examples illustrating more of the deeper levels in the classification and areas of application. The paper is rounded off in a discussion concluding on the presented work and listing subjects of further research.

2. Method

The method for creating the consolidated production process classification scheme presented in Section 4 is essentially
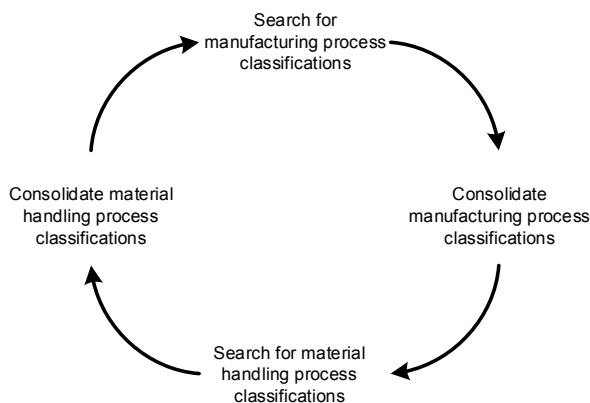
Fig. 1. Simple overview of the method used for creating the classification scheme.

a search process interwoven with a consolidation process. As illustrated on Figure 1, the method was initiated with a search for a manufacturing taxonomy, classification or ontology, followed by a consolidation process for the discovered classification. The same was then done in search for a material handling classification. It can be considered a simplified adaptation of the design science research cycles [6], and was chosen in an attempt to balance the search for manufacturing and material handling processes. A full round of Figure 1 constitutes one iteration of the method.

The search process was a straight forward search on a number of keyword combinations in a variety of databases followed by pearl-growing. Overall, the following strings represents the search process for manufacturing and material handling process classifications respectively.

- `(manufactur* OR production) AND (taxonomy OR ontology OR classif* OR vocabulary)`
- `handling AND (taxonomy OR ontology OR classif* OR vocabulary)`

The consolidation process focused on determining how well a discovered classification fit a set of criteria for the consolidated classification, and how well it aligned with previously discovered classifications and the current iteration of the consolidated classification. In particular, this included looking for discrepancies in how processes were grouped, and processes existing in one classification and not another.

Prior to initiating the method, four criteria for the classification scheme were set up. The consolidated classification scheme should:

1. include both manufacturing and material handling processes.
2. have a clear differentiation between classes.
3. have a manageable number of levels.
4. be function based, i.e. as independent of means/equipment as possible.

An exact number of levels is not specified in the criteria. Rather, the number of levels was evaluated on an individual basis for each classification, largely based on how easy it was to get an overview of and navigate a given classification.

Having a classification scheme be independent of means or equipment may make it easier to identify alternatives to existing solutions, and commonality across production systems that may not seem to have much in common in terms of equipment.

In the end, the decision to group processes should be, as Ashby [7] puts it: "the attributes of one family differs so greatly from those of another that, in assembling and structuring data for them, they must be treated separately."

3. Classification and Taxonomy Review

Several existing classifications and taxonomies were reviewed in order to create the consolidated classification scheme. Table 1 provides an overview of the six key process classification schemes and taxonomies used in this study: four for manufacturing (mfg.) and two for material handling (MH). Sections 3.1 and 3.2 introduce the manufacturing and material handling taxonomies respectively. None of the reviewed classifications included both manufacturing and material handling processes, meaning criteria 1 was not fulfilled by any of the existing classifications.

While the six sources of taxonomies listed in the table are the main contributors to the classification scheme presented in Section 4, other taxonomies and literature has been considered as well. Some have influenced the classification scheme, but are not included in the table. For instance, Apple employs the notion of utility to differentiate between manufacturing and material handling [8]. Rather than simply noting one category of processes as value adding or non-value adding, we will use utility to describe the type of value added. In this vein, manufacturing processes add "form utility" by changing the shape or composition of a workpiece, while material handling processes add "time utility" and "place utility" by making a workpiece available at the desired time and place [5,8].

Others, such as Karni and Rubinovitz [9] and Bouh and Riopel [10], focus on describing relevant attributes or capabilities for material handling equipment and processes, aligning well with Ashby's process attributes and records [7].

3.1. Manufacturing Classifications

There is generally a consensus among the reviewed taxonomies on how to differentiate between manufacturing processes. One of the primary parameters is whether the process is a shaping or non-shaping process, as indicated by Todd et al. [13] and seen in the three other taxonomies as well [7,11,12]. Following this distinction, there are a number of ways to group processes.

Todd et al. [13] group shaping processes into mass-reducing, mass-conserving and joining. Non-shaping processes are grouped into heat treatment and surface finishing. This grouping of processes continues, resulting in up to eight levels, with e.g. mass-conserving processes being grouped for another five levels. While this makes the differentiation clear at all levels, the taxonomy can be difficult to follow due to the sheer amount of levels. The taxonomy of Todd et al. is not entirely equipment-based but not entirely independent of equipment either. Depending on the specific process group, the underlying processes may be more or less equipment-based. For instance, the high energy beam machining group contains electron beam Cutting, laser beam cutting and ion beam cutting. These three beams essentially carry out the same function of cutting, also performed by processes in the single-point and multipoint cutting groups.

Table 1. Overview and comparison of key process classifications and taxonomies considered for this paper.

	DIN 8580 [11]	Ashby [7]	Kalpakjian and Schmid [12]	Todd et al. [13]	VDI 2860 [4]	Kay [5]
Classification	Six mfg. process families: • Primary shaping • Forming • Separating • Joining • Coating • Change material properties	Three mfg. process families: • Joining • Shaping • Finishing	Six mfg. process families: • Casting • Forming and shaping • Machining • Joining • Finishing • Micro- and nanofabrication	Five mfg. process families: • Mass-Reducing • Mass-Conserving • Joining • Heat Treatment • Surface finishing	Five MH process classes: • Storage • Change quantities • Movement • Securing • Inspection	Five MH process families: • Transport • Positioning • Unit load formation • Storage • Identification and control
Differentiation	Creation, reduction and preservation of cohesion.	Progress/flow through mfg.	Primary, secondary, finishing and others.	Shaping/Non-shaping.	Partial, elementary and composite functions.	Five primary MH functions.
Comment	Established standard. Clear differentiation.	Introduces terms for levels.	Comprehensive. Less strict in grouping.	Comprehensive. Clear differentiation.	Independent of means. Withdrawn.	Simple. Equipment-based.

The German standard DIN 8580:2003–09 (henceforth DIN 8580) [11] uses three levels (main group, group and subgroup). It differentiates between main groups using the material state (shapeless/liquid, solid) of the workpiece, coupled with creation, reduction and preservation of coherence in the workpiece. For instance, primary shaping refers to processes making a solid body from a shapeless material by creating cohesion, and joining is the assembly of two or more solid bodies. This essentially skips shaping/non-shaping as a standalone level, but incorporates it implicitly. Several of the groups and subgroups are referred to as separate DIN standards, where they are detailed further, making DIN 8580 itself a less comprehensive taxonomy than e.g. [13]. DIN 8580 is somewhat independent of equipment, with the tensile forming group including functions such as lengthen and widen, and other groups including functions at a similar level. However, the machining group is split into two, depending on whether the cutting edge (tool) is geometrically defined (e.g. turning, drilling) or undefined (e.g. honing, beam machining).

Ashby [7] firstly group processes into the order in which they typically occur during manufacturing. Primary shaping for creating shapes, secondary processes for adding or enhancing features, joining for assembly and surface treatment for finishing. Ashby then creates a hierarchical classification, listing a total of four process levels (universe, family, class and subclass), and a fifth level describing the attributes of each process. A set of these attributes constitutes a process record. Each process can have a number of process records representing different areas of application for each process. Ashby's classification follows the example set by Todd et al., and somewhat blurs the line between function and equipment at higher levels of detail.

Kalpakjian and Schmid [12] group processes in six process families, each with three underlying classes, and subsequently provide a comprehensive description of each process included in the classification. These descriptions do not, however, always follow the initial classification. Instead, the descriptions are often grouped according to the material they are applicable to, e.g. metals, ceramics or plastics. This makes the differentia-

tion somewhat inconsistent at higher levels of detail. Similarly to Todd et al. and Ashby, Kalpakjian and Schmid's classification is not strictly function or equipment-based. In general for the four classifications above, as the level of detail increases so does the dependency on physical manufacturing equipment in order to differentiate between processes.

3.2. Material Handling Classifications

Most of the reviewed material handling taxonomies is equipment-based and often based upon the four primary material handling functions listed by Chu et al. [14]. These four functions deal with the manipulation of materials in, between and out of production systems. Transport processes move materials from one location to another, while positioning processes move materials at a single location or workstation. Unit load formation processes deal with restriction of materials so they maintain integrity when handled (e.g. packaging and wrapping), and storage processes hold or buffer materials over a period of time. Kay adds a fifth function dealing with collection and communication of information used in the coordination and flow of materials in production [5]. Addition of the "Identification and Control" processes marks the difference in why Kay [5] is included in the table over Chu et al. [14].

VDI 2860:1990–05 (henceforth VDI 2860) splits the Material Handling process category into three families (Handling, Storage(Hold) and Transport) and focuses on the Handling family, listing five process classes [4]. In contrast to other reviewed Material Handling taxonomies, VDI 2860 is independent of equipment and means, using only elementary and composite functions. VDI 2860 also introduces a collection of symbols to go with each of the classes, making it possible to describe systems, processes and equipment through a sequence of unique symbols.
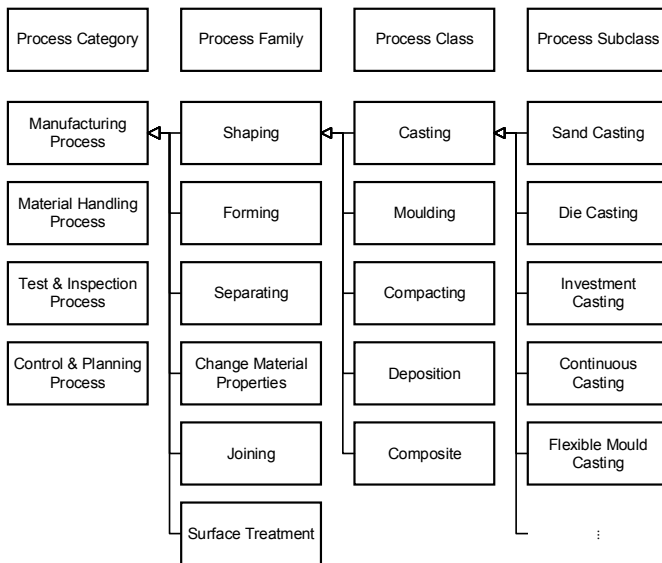
Fig. 2. Overview of the classification scheme, partially expanding the manufacturing category and shaping family.

4. Results

Figure 2 names the various levels of the classification scheme with part of the handling family expanded. For the sake of simplicity, relations to the levels (category, family, class and subclass) are not shown, but "Manufacturing Process", "Material Handling Process" etc. are all process categories, "Handling", "Transport" etc. are process families and so on. This naming convention has been adapted slightly from Ashby [7], who uses "universe" instead of "category".

Of the process categories, families, classes and subclasses explored during this study, the total currently comes to:

- 4 process categories
- 16 process families
- 53 process classes
- 232 process subclasses

These numbers are expected to change as more branches of the classification are fleshed out and changes inevitably occur during revisions. The classification scheme has been modelled using the Protégé resource [15]. Figure 3 shows an excerpt of the asserted hierarchy of the classification exported from Protégé, expanding the casting class. The complete classification scheme in its current state is available as an OWL file[1]. In the following sections, the four process categories and their related families are described.

4.1. Manufacturing Processes

Processes in the manufacturing category add utility to a workpiece by changing the form or make-up of materials constituting the product. The manufacturing process category consists of six process families listed below.

- Shaping: Processes creating a solid body from an otherwise shapeless material by creating cohesion. Has five process classes.

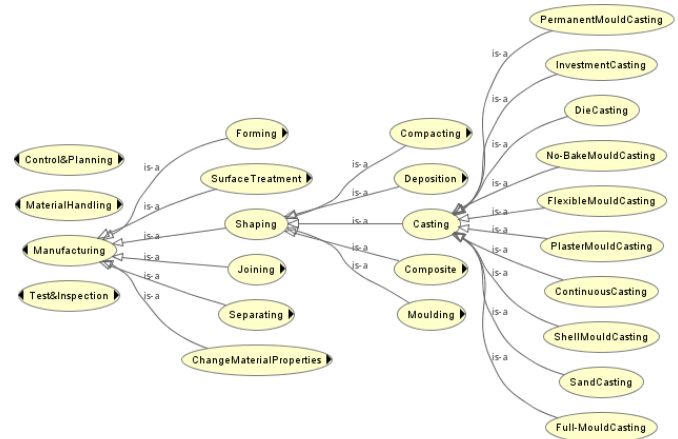[1]PPC.owl at https://goo.gl/azFpJe

Fig. 3. An excerpt of the asserted hierarchy of the classification scheme exported from Protégé showing all subclasses of the casting class.

- Forming: Processes changing the shape of a solid body while maintaining the mass and cohesion of the body. Has seven process classes.
- Separating: Processes changing the shape of a solid body while reducing cohesion of the body partly or wholly. Has eight process classes.
- Change Material Properties: Processes modifying the properties of a solid body prior to or after it has achieved its shape. Has nine process classes.
- Joining: Processes joining or assembling two or more geometrically determined solid bodies, or joining one body to a formless material. Has eight process classes.
- Surface Treatment: Processes modifying the surface of a solid body in order to enhance properties or appearance by applying an adhering layer of a shapeless material or mechanically modifying the surface. Has six process classes.

As an example, the shaping family and casting class has been expanded and illustrated in Figure 2. These classes deal with the initial creation of shapes rather than the modification of shapes taking place in the other five process families. Casting processes involve a liquid being poured or forced into a mould followed by cooling and solidification. Casting differs from moulding due to the low viscosity of materials used in casting compared to moulding, and the resulting pressure required to make the material flow. Compacting processes create shapes by pressing powdered material into a die. Deposition processes gradually deposit material to create a shape (e.g. fused deposition modelling) and composite processes create shapes using sheets or filaments of material.

The casting class includes ten subclasses, all included in one class because they essentially perform the same function, but differ in attributes and capabilities. No attributes have been explicitly defined for this classification scheme, but Ashby [7] suggests some generic attributes such as material, shape, size, tolerance, roughness, minimum batch size etc. Such attributes would assist in the selection and comparison of processes, while the classification itself can identify alternatives and similarities between processes.

4.2. Material Handling Processes

Processes in the material handling category add utility to a workpiece by ensuring workpieces and material are available at
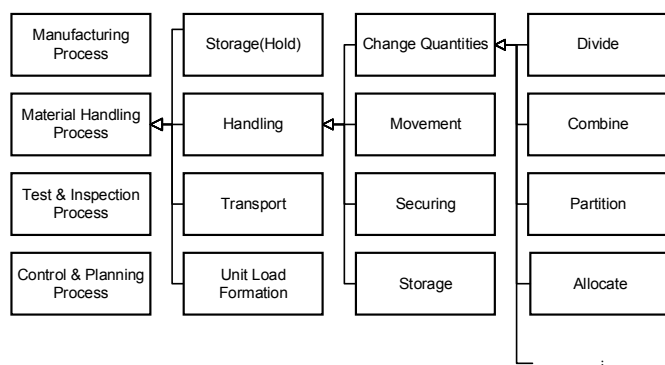
Fig. 4. Partial expansion of the handling family and change quantities class.

the right place at the right time. The material handling category consists of four process families listed below.

- Transport: Processes moving material from one location to another outside individual production systems.
- Storage(Hold): Processes storing materials separate from individual production systems.
- Handling: Processes moving material as part of an individual production system. Has four process classes
- Unit Load Formation: Processes restricting materials to maintain integrity during handling. Has four process classes.

Note that the transport, storage(hold) and unit load formation families have not been covered in-depth in this study. As an example, the handling family and change quantities class has been partially expanded and illustrated in Figure 4. This class and the other three classes within the family are essentially the classes proposed in VDI 2860 [4]. Change of quantity processes involve the division into (and union of) partial quantities. Storage processes deal with the storage of required materials at or near the location they are to be used (e.g. bins or magazines with components). This differs from the storage(hold) process family, as these processes deal with centralised storages (e.g. bin shelving, storage racks and warehouses). Movement processes involve the movement of partial quantities during production, including movement between stations in a production system, and positioning at a single station. Securing processes preserve a defined state for a partial quantity by securing a spatial arrangement when handling a body (e.g. clamping and holding a workpiece).

The change quantities class consists of seven subclasses for creating quantities, including both processes dividing/combining quantities based on the number of workpieces, and processes sorting workpieces based on features. As with the casting process class, no attributes have been explicitly defined, but some generic attributes such as material, shape, size and material integrity are applicable. The value of each attribute will naturally depend on the specific equipment.

4.3. Control & Planning Processes

The control and planning process category is one of two relatively unexplored categories for this iteration of the process classification scheme. This category of processes was separated from the other on the basis that it does not strictly provide form utility or time and place utility, but rather manages, balances

and facilitates these. In its current state it consists three process families that have yet to be broken down into classes and subclasses. The three families are: business planning and control (alternatively Enterprise Resource Planning), covering core business processes; manufacturing operations and control, covering operations management and MES related processes; line control, covering control of individual production systems or lines.

4.4. Test & Inspection Processes

Test and inspection processes have been separated from the material handling category (where it appears in [4] and [5]) on the basis these processes do not provide time and place utility like the other processes in the category. Instead, they provide a form of information utility, supporting the other three categories by capturing and communicating information about workpieces. In its current state, the category consists of three process families that are not yet broken down into classes and subclasses. These are: inspection, covering the inspection or measuring of a workpiece's various properties; functional test, covering tests on whether a workpiece or assembly can carry out its intended function; performance test, covering tests on how well a workpiece or assembly can carry out its intended function over an extended period of time.

5. Applications

The classification scheme presented in this paper is primarily intended to assist in the mapping of production systems for the platform development process. Part of this is simply to agree on a common vocabulary, e.g. a compacting process is called a compacting process and not a compaction process. Eventually, the classification will also denote which attributes should be specified for each process. This will ensure that the processes and their capabilities are described in a uniform manner.

Mapping and subsequent comparison of production systems is a useful way to identify solutions, and determine which solutions have been more or less successful and effective in the past. To gain the most from mapping and comparison, they must be carried out in a consistent and coherent manner. Two different people looking at the same system will often have different interpretations of the system. This subjectivity can be minimised by providing a classification of processes, and potentially tools utilising the classification, e.g. an app for mapping production systems. In order to minimise this subjectivity and describe the functions of a production system and individual equipment, VDI 2860 proposes a collection of unique and recognizable symbols for representing material handling processes [4]. Having unique and recognizable symbols for each function or process in the classification could enable instant digitalisation of documents used to map a specific production system. In general, this would speed up the process of mapping and comparing multiple production systems.

Commonality as a basis for a product platform has proven effective in a number of industries, including automotive, to mention one [16]. Defining and identifying commonality is not always straight forward, however. The classification may assist in the identification of commonality on the basis of the processes and functions carried out during production.

Finally, the classification may be further developed into an ontology defining capabilities and linked with a product ontology defining part characteristics as part of a modelling framework. This would enable companies to model their specific production equipment and product components in company-specific ontologies, eventually helping companies decide whether a given product requires purchase of new equipment, or if the product can be manufactured on existing equipment.

6. Discussion & Conclusions

By reviewing and consolidating a number existing manufacturing and handling classifications and taxonomies, this study outlines a consolidated classification scheme. The presented classification scheme for processes in the production of discrete products consists of four process categories, grouping processes into manufacturing, material handling, test and inspection or control and planning processes. This distinction between categories is based on the type of utility added to a workpiece or product by the processes in each category.

During this study, a decision was made on calling the resulting workproduct of this study a classification, rather than a taxonomy or an ontology. van Rees [17] provides an overview of the differences between the three terms, with the main difference between the three being a classification grouping entities according to external criteria, a taxonomy grouping entities according to internal criteria, and an ontology assigning and defining properties of entities and their relationships. As such, in its current state, the workproduct of this study falls under the classification group, but as work progresses and more information is added, it will become an ontology.

With a number of production systems decomposed and each system and its constituent elements classified in accordance with a coherent and consistent scheme, identifying the commonality or similarity between systems on multiple levels should become possible. Commonality optimisation approaches may then be used to identify candidates for platform development. While some of these may be obvious candidates without the need for an optimisation algorithm, candidates may exist where not previously considered. An example of such, is the method for product family formation presented by Kashkoush and ElMaraghy [18], where bill-of-process trees could potentially be used to form process or production platforms.

In order for these optimisation approaches to be applied, the classification scheme presented in this study should be developed further, towards becoming a taxonomy or ontology. To do so, attributes and process capabilities must be added to the current scheme, and additional relations between the processes identified and included.

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