Inventory classification based on decoupling points

Joakim Wikner*1 and Eva Johansson

Department of Industrial Engineering and Management, School of Engineering, Jönköping University, Jönköping, Sweden

(Received 14 April 2015; accepted 27 June 2015)

The ideal state of continuous one-piece flow may never be achieved. Still the logistics manager can improve the flow by carefully positioning inventory to buffer against variations. Strategies such as lean, postponement, mass customization, and outsourcing all rely on strategic positioning of decoupling points to separate forecast-driven from customer-order-driven flows. Planning and scheduling of the flow are also based on classification of decoupling points as master scheduled or not. A comprehensive classification scheme for these types of decoupling points is introduced. The approach rests on identification of flows as being either demand based or supply based. The demand or supply is then combined with exogenous factors, classified as independent, or endogenous factors, classified as dependent. As a result, eight types of strategic as well as tactical decoupling points are identified resulting in a process-based framework for inventory classification that can be used for flow design.

Keywords: decoupling points; inventory classification; planning and control; materials management

1. Introduction

Increasing customer requirements for customization, cost issues, and ever shortening product life cycles result in a dynamic behaviour and structural complexity of the logistics system that are very demanding. The decisions are not only a complex matter due to the intricacy of each individual decision but also the sheer volume of decisions adds weight to the burden. In addition, the reduction of inventories in the logistics systems leads to stronger dependencies across the material flows, which increases the risk for knock-on effects of disturbances as pointed out by, among others, Goldratt and Cox (1984). Considering these characteristics in combination, it is obvious that logistics managers need tools to simplify and automate decision-making. Important concepts in this context are abstraction, in order to retain only information that is relevant for a particular decision problem, and aggregation, to focus on groups of entities where the same decision can be implemented.

From a decision-maker’s perspective, the implications of applying abstraction (selecting relevant information) and aggregation (grouping of information) are significant. Abstraction is usually applied through hierarchical decision-making. At the lowest level, detailed decisions are usually made with a local and short-term focus. At higher levels, issues of more strategic character are handled. Typical examples at the strategic
level are to focus on constraining resources and materials critical to customer service. Aggregation can be applied by aggregating decision problems and making a decision based on a key property of the aggregate, such as a product group, and then more or less automatically applying the decision to all products of that product group. The terminology used in this paper refers to this type of aggregation as classification. By classifying an item as a specific type due to some of its properties, a group of items sharing this property is created.

These two concepts, abstraction and aggregation, are the theme of this paper. Item and inventory classifications of different types are very common in logistics management (see, e.g. Broeckelmann, 1999), and our ambition is to further emphasize the importance of a process perspective in this context. Previously, much focus has been on classifications using item properties as a point of departure, e.g. ABC classification, but with an additional process perspective, further support can be provided to logistics management. The purpose of the research presented in this paper is to develop a process-based framework for inventory classification. The application of the framework in planning and control is discussed in order to show how the results can be used.

The paper is structured as follows. Next, a general overview of the inventory management context is provided in terms of decoupling points. The concept of supply system is introduced and some key properties of decoupling points related to replenishment and withdrawal are defined. Thereafter, a generic structural model for logistics systems is introduced to identify four key delivery strategies and their respective positions of the two critical decoupling points of strategic importance. Finally, a process-based approach to inventory classification is derived from the discussion on strategic and tactical decoupling points, followed by managerial implications for planning and scheduling, and some ideas for further research.

2. Decoupling points and material flows

The context of material flows is here referred to as a supply system that can be described as a set of resources transforming raw materials into finished goods. Throughout the material flow, resources interact in the transformation process to create value in terms of form, time, and place. In an ideal state, the material flow is continuous and one piece (Ohno, 1988, p. 96) meaning that there is a steady and even flow where all the resources are synchronized and performing with a minimum of balancing loss in the system. This ideal state is, however, rarely possible to realize in the complete supply system. Usually, this type of material flow is limited to a set of resources performing a number of steps continuously but in a context of only a manufacturing cell or a line. In the context of place transformation, the only case where continuous flow can be achieved, except for in pipeline transportation, is through aggregation of several material flows to, for instance, a truck load, thus providing one-piece flow for each separate material flow. Using common lean terminology, this kind of well-defined section of one-piece flow is referred to as a process (Rother & Shook, 2003, p. 18). Each process then represents transformation and replenishes a point of inventory downstream and withdraws materials from one or more other points of inventory upstream. At a ‘micro’ level, the material flows can therefore be modelled as a set of stock points, i.e. inventories, each connected with processes that withdraw materials and processes that replenish materials. Each inventory can hence be seen as a point that decouples two processes (replenishment and withdrawal) and enables them to act somewhat independently. This kind of decoupling point is referred to as a DP (this definition is in line with the general
perception of the concept, see, e.g. Blackstone (2008). The supply system can hence be modelled as a set of DPs that interact through replenishment and withdrawal processes. Note that a process that is a replenishment process for one DP can be a withdrawal process for another DP. The only exceptions are the replenishment processes related to supply external to the supply system (e.g. external suppliers) and withdrawal processes that are external to the supply process (e.g. external customers).

2.1. Decoupling points categorization

The concept of DP is a core component in the management of material flows. Considering different combinations of unexpected and expected events, related to replenishment and withdrawal, for each and every DP results in a very demanding challenge for management since the number of DPs in an enterprise or supply chain is staggering. It is very difficult in all realistic settings, at least with today’s technology, to control each and every DP to any greater extent. To handle this complexity, the DPs can be differentiated into categories. In particular three categories play a key role in materials management; they are here referred to as operational, tactical, and strategic:

- **Operational DPs** connect transformation points in the physical material flows and are, for example, known as queues in front of resources.
- **Tactical DPs** are related to materials given a unique identifier, usually referred to as item number or part number. Introducing this identity code enables item-level materials management.
- **Strategic DPs** are a subset of all tactical DPs that play a role of critical importance to the interface of the supply system and its context.

2.2. Decoupling points and planning and scheduling

Strategic DPs relate to items that are exposed to external influence on the withdrawal side, such as customer orders, or on the replenishment side, such as purchase orders. External demand is not possible to derive from demand for other items and is hence usually unpredictable in terms of both quantity and timing. Classifying items as exposed to external influence or only as internally affected corresponds to the classification in terms of dependent and independent demand, which is the fundamental principle behind materials planning (Vollmann, Berry, Whybark, & Jacobs, 2005, p. 134). Demand for an item that can be derived from demand for other items is in this context referred to as dependent demand (DD). In its most straightforward application, demand for a component is calculated as the demand for the parent item multiplied by the explosion quantity. Demand that cannot be calculated in this way but is directly affected by external demand is thus classified as independent demand (ID). This classification of demand has a long history and is particularly associated with material requirements planning, MRP (Orlicky, 1975), of which backward scheduling is a key concept. As this scheduling approach is performed, the demand for the next level of items is calculated in the bill-of-material (BoM) explosion process. Many items with DD may also have a certain proportion of ID, if they, for example, are sold separately as spare parts besides being used in the production of another parent item. In summary, DD items are exposed to internal demand and hence of a less strategic nature. ID items, on the other hand, are exposed to external demand, e.g. customer orders, and due to their strategic nature
correspond to strategic DPs. The similarities between independent and strategic DPs have so far been covered from a demand-based perspective but, as will be shown below, the corresponding similarities can also be identified from a supply-based perspective. Integrating the demand-based and the supply-based perspectives results in a more comprehensive approach to the classification of DPs.

3. The logistics system

The basic supply system outlined above corresponds to an inventory subsystem related to one DP connected with a replenishment process and a withdrawal process. In isolation, this is a relatively simple entity where item-based inventory management can be applied. An inventory subsystem is, however, usually a part of a larger logistics system consisting of a set of connected inventory subsystems. As the complete logistics system is considered, a range of dependencies is introduced, which increases the complexity of the decision problem. Instead of dealing with single-item inventory management, the decision-maker is facing a scenario with a network of inventory subsystems that interact with each other, and to some extent also interact with the context of the complete logistics system. This type of system also corresponds to the logical entity introduced by Wikner (2014) as a supplement to the traditional actor-based approach to flow design.

Such a complex decision problem is very difficult to handle with a monolithic model and therefore requires some kind of hierarchical approach to system analysis providing the system analyst with an appropriate abstraction level for each decision. Above, the lower abstraction level in terms of one individual DP was introduced. Next, the higher abstraction level is introduced involving the key concepts of strategic DPs and strategic supply systems. In particular, we are interested in DPs exposed to exogenous influence. Exogenous influence refers to external influence, of which the customer order is the most important. Internal influence, on the other hand, is dependent on other internal events and is thus endogenous.

3.1. Demand and supply categories

To discriminate between different DPs with the objective of identifying the vital few, it is necessary to identify the DPs exposed to exogenous influence. Dependent and independent demands (DD and ID) were described earlier and are classified in Table 1. To the authors’ knowledge, there is no corresponding general conceptual framework for bottom-up approaches where the supply is the driver in the process. More specific approaches do, however, exist, such as the forward flow scheduling approach of process flow scheduling (Taylor & Bolander, 1994). Taking supply as the point of reference would result in employing a forward scheduling approach to generate supply for the next higher level in the BoM. Note that a common denotation of levels in a BoM is that

<table>
<thead>
<tr>
<th>Demand</th>
<th>Supply</th>
<th>Independent</th>
<th>Dependent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Supply that must be estimated (purchase orders)</td>
<td>Demand that must be estimated (forecast and customer orders)</td>
<td>Supply that can be calculated (forward scheduling)</td>
</tr>
</tbody>
</table>
the top level is 0 and for each subsequent lower level the level number increases. In analogy with the demand-based concept, this is referred to as dependent supply (DS). Using the concept of forward scheduling, the supply of material on level \(i\) in the BoM would be dependent on supply on the next lower level, level \(i + 1\), during the scheduling phase. In a backward scheduling scenario, the demand for items on level \(i\) would be dependent on the demand for items on the next higher level, level \(i - 1\). The key property of DD and DS is that they both can be calculated based on the available endogenous information of the logistics system, such as lead times and available inventory.

The description above shows the clear analogy between DS and DD. The next step is to identify independent supply (IS) as an analogy to ID. This analogy is, however, not as clear-cut, but we define supply from a source outside the logistics system as IS since it is outside the strict control of the logistics system. Control can cover a complete manufacturing network or just a single site. The important aspect is that within the controlled supply system there is no need for traditional purchasing orders; instead internal orders (sometimes referred to as distribution orders) can be used covering both the demand process from one DP and the supply process of another DP. In summary, four types of drivers can be identified in the material flows as in Table 1, i.e. the intersections between supply/demand and independent/dependent.

Based on these two types of independent drivers (IS and ID), two types of corresponding DPs can be identified; they are discussed in the following two sections.

### 3.2. Demand-based decoupling point

Delivery strategies such as make-to-stock (MTS) and make-to-order (MTO) play a key role in providing an appropriate balance between efficiency and responsiveness in meeting market demand (see, e.g. Chopra & Meindl, 2007). The baseline for designing the appropriate strategy in this perspective is the relation between the delivery lead time (D), requested by the market, and the total supply lead time (S) within which the system needs to produce the output. The ratio between these two lead times is critical; it was first identified by Shingo (1981) as the D:P relation. Mather (1984) changed the relation to the inverse for practical reasons and since then it is known as the P:D ratio or P:D relation. Shingo used P as he was referring to product lead time. In a similar vein, the more general supply lead time is used and thus referred to as S (see, e.g. Wikner, 2014). S more explicitly involves, for example, also purchasing and distribution lead times. If S is shorter than D, all supply activities can be performed while the customer is waiting. But when S is longer than D some activities must be performed in advance to create semi-processed parts to be used when the customer order arrives. The supply system is thus split into two parts corresponding to two subsystems. The subsystem supplying semi-processed parts is performed before the customer order arrives and is therefore forecast-driven. The second subsystem uses the semi-processed parts in stock to deliver on the customer order. This is sometimes referred to as customer-order-driven (see, e.g. Hoekstra & Romme, 1992) but also as demand-driven (see, e.g. Christopher, 1998). The semi-processed parts are kept in stock at a decoupling point that is known as the customer order decoupling point, CODP, (see, e.g. Giesberts & van der Tang, 1992) but also as order penetration point, OPP (Sharman, 1984) or simply as decoupling point (Hoekstra & Romme, 1992). The CODP has been defined in a number of different ways but, as summarized by Wikner (2014, p. 195), ‘[t]he customer order decoupling point (CODP) separates decisions about initiating flow based on speculation on future customer orders from commitment against actual customer orders’. Using these
three building blocks (forecast-driven supply system, CODP, and customer-order-driven supply system), the supply system can be depicted as in Figure 1, where a consumption system has been introduced as an origin of demand and to represent the customers of the supply system. The diamond is used to represent the CODP in line with the guidelines suggested by Wikner (2014).

Considering a customer order arriving in the supply system of Figure 1, the customer must accept to wait during the time it takes to perform the customer-order-driven supply system (during the lead time D). This system lead time could involve activities outside manufacturing (see, e.g. Rudberg & Wikner, 2004). To replenish the CODP, some kind of forecast is necessary since customer orders are assumed to arrive in time to perform only the customer-order-driven supply system in Figure 1. The forecasting can be performed at the end-item level but if any parts are shared between different end items it is easier, due to aggregation effects reducing the coefficient of variation in demand, to forecast at the CODP on semi-processed parts. This corresponds to defining the CODP parts as subject to ID as shown in Figure 1. Activities downstream of the CODP may be performed under certainty of demand since a customer order is driving the activities. The parts at the CODP must, however, be produced to forecast since they are expected to be available at the moment the customer order arrives.

### 3.3. Supply-based decoupling point

The CODP emphasizes the relation between the delivery lead time D and the supply lead time S, and hence investigates the demand-related properties of S but does not provide any further information on what actually constitutes supply. Taking a supply perspective, an important concept is to what extent the complete supply system is integrated. In this case, the focus is on inventory and materials management and therefore also the level of integration is defined based on the level of control that can be exercised on the supply system. In an integrated supply system, the complete set of supply activities would be controlled as one entity. If, however, the supply system is not integrated, the supply system could be separated into two subsystems, here referred to as one controlled subsystem and one uncontrolled subsystem, see Figure 2. A hexagon is used to illustrate the purchase order decoupling point (PODP) in line with Wikner (2014). The uncontrolled subsystem is out of control reach for the controlled subsystem.

An example is a component supplier of a company that supplies parts per order and where there is no further integration. A purchase order is sent to replenish the inventory when required. In this case the supplier would be modelled as an uncontrolled system including not only the supplier but also all the supplier’s suppliers, etc. Using this
approach, a recursive systems definition is obtained where the controlled supply system and how it interacts with the consumption system is the focus. Remember that from the uncontrolled supply system perspective, the controlled supply system would represent the consumption system as depicted in Figure 3. This is because all upstream activities not covered by the controlled supply system are included in the uncontrolled supply system.

Within the controlled supply system, there is full transparency in terms of planning and execution which enables a cost-efficient allocation of decoupling points, i.e. buffers, from a system’s perspective. The uncontrolled supply system does, however, not provide this level of transparency by definition. Since control cannot be exercised on this system by the controlled supply system, the only way to manage unexpected events occurring in this system is to introduce a buffer explicitly targeting these properties and decoupling the controlled system to protect it. As shown by Lee (2002), this relation must be carefully designed and alternative strategies for minimizing unexpected events should be considered, but if uncertainty prevails it must be handled with some type of buffer, otherwise customer service and/or cost efficiency will suffer. Since the relation with the uncontrolled supply system usually is through some kind of purchase order, we introduce the term PODP for this kind of buffer, as in Figure 2. Activities within the controlled supply system are usually coordinated by production orders and distribution orders but when it comes to coordinating with an external system, the relation is usually handled through a purchase order. This model is also related to the lead time based analysis performed by Wallin, Rungtusanatham, and Rabinovich (2006). They related the delivery lead time D to production time P in the spirit of Shingo (1981), but then made a distinction between the part of P covered by the supplier and the part covered by the focal company. Using this approach, different strategies for inventory management of purchased material were identified, but here the emphasis is on the complete supply system structure and not only purchased materials at the PODP. In Wallin et al.
The focal company is the unit of analysis. Here, however, the unit of analysis is a supply system, and to emphasize what specific supply system is considered it may be referred to as the focal supply system. In Figure 2 the focal supply system would correspond to the controlled supply system. A similar approach to dividing the supply system into subsystems based on exogenous influence has also been investigated by Wikner (2005), but then from the perspective of efficiency and responsiveness.

The PODP can hence be defined as follows: ‘[t]he PODP separates decisions about delimiting flow based on what is external to the logical entity from what is internal and hence controllable’ (Wikner, 2014, p. 199). This indicates that the uncontrolled supply system provides input to the controlled supply system. This input contains more uncertainty compared to what is perceived from the controlled supply system and thus requires some kind of estimation (forecasting), which also is the key property of IS, see Table 1.

### 3.4. Modelling the logistics system based on delivery strategies

The fundamental building blocks of the logistics system have been defined above and are summarized in Figures 1 and 2. Basically, the properties of the supply systems highlighted are type of driver, related to CODP, and level of control, related to PODP. Each particular logistics system has its own unique characteristics based on its history, market conditions, available resources, etc. There are, however, some generic configurations that can provide a baseline for illustrating how the constructs introduced above can be employed to represent an enterprise from a logistics perspective. The two fundamental configurations used here are the completely customer-order-driven system (MTO) and the completely forecast-driven system (MTS). The third system (assemble-to-order, ATO) represents a compromise system with elements of both MTO and MTS (Wemmerlöv, 1984). The fourth system, finally, involves also the possibility of outsourcing not just forecast-driven activities to uncontrolled supply systems but also customer-order-driven activities; this is referred to as purchase-and-make-to-order (PMTO) (Hoekstra & Romme, 1992).

#### 3.4.1. Make-to-stock (MTS)

When the MTS strategy is used, all activities are forecast-driven (with the possible exception of some picking and delivery activities). In this case, the CODP is positioned as far downstream in the material flow as possible. No activities are customer-order-driven and
usually the master schedule (see, e.g. MRPII) or pacemaker (see, e.g. rate-based master scheduling as in lean) is positioned at the end-item level, where ID is present. This allows for a materials planning approach based on DD (backward scheduling), which is the most common approach in this setting, for all items down to the PODP. The PODP hence represents the extension of the integrated planning and control approach as shown in Figure 4. In Figures 4–7, the dashed vertical arrows represent exogenous input to the supply system. The dashed horizontal lines represent endogenous propagation of demand and supply respectively, in the direction indicated by the arrow.

3.4.2. Make-to-order (MTO)

The second fundamental configuration corresponds to the MTO strategy, where all activities of the controlled system are customer-order-driven. When the customer order is received, the customer waits until the product is finished. The planning approach can be based on DD (as in MRP), where the end item is master scheduled and DD is calculated for all other items down to the CODP. A preferred scenario would, however, in some cases be to start with the CODP items availability and then to forward schedule all items (DS) up to the end item to provide, for example, information about delivery capability. This process would then preferably also involve finite loading considering any finite capacity to provide reliable delivery dates. Since the CODP here is positioned at the beginning of the controlled supply system, it coincides with the PODP as shown in Figure 5.

3.4.3. Assemble-to-order (ATO)

A preferred strategy in many cases is to establish a level in the BoM that allows for modularization. Different modules can then be used in a multitude of configurations enabling a mass customization approach. Modules are then produced to forecast using a standard MTS ‘sub-strategy’, whereas the final assembly is customer-order-driven and similar to the MTO approach. Setting the two models of MTS (Figure 4) and MTO (Figure 5) in tandem results in an ATO scenario as in Figure 6. The CODP is positioned between the forecast-driven and the customer-order-driven supply systems, and the PODP is also in this case positioned at the interface between the uncontrolled and the controlled supply systems.

![Figure 5. Modelling make-to-order (MTO) supply systems.](image-url)
3.4.4. Purchase-and-make-to-order (PMTO)

If only the CODP is considered, the three strategies identified above, MTS, MTO, and ATO, are key scenarios. Each strategy consists of a unique combination of forecast-driven and customer-order-driven supply systems. Taking a broader perspective and also considering that the delivery lead time $D$ may extend beyond the lead time of the controlled supply system provide leeway for a fourth scenario. This scenario involves an external supplier (here referred to as an uncontrolled supply system) that is customer-order-driven, as illustrated in Figure 7. There are now two customer-order-driven supply systems separated by the PODP, and the CODP is positioned upstream of these two supply systems. This is a possible, if not always desirable, strategy as some activities performed while the customer, i.e. the consumption system, is waiting are performed beyond the control of the supply system responsible for delivery to the customer. A possible approach in this case would be to seek to integrate, i.e. ‘in-source’, the uncontrolled customer-order-driven supply system and, if this is not possible, to establish a safety lead time at the PODP, unless all uncertainties between the CODP and the PODP can be eliminated.

3.4.5. Summary of the four logistics system configurations

To conclude the discussion on logistics systems configured based on the concepts of customer-order/forecast-driven and uncontrolled/controlled, the configurations are summarized in Table 2. The four concepts provide four possible configurations of supply systems as represented by the columns. In addition, it is also required, by definition, that
certain precedence constraints are fulfilled. A forecast-driven supply system should not be positioned downstream of a customer-order-driven supply system. This is because the supply systems are positioned along a time axis and if it is possible to be customer-order-driven, this is assumed to always be the preferred option. Why forecast-driven if actual demand is available? The second precedence constraint is that uncontrolled supply systems are positioned upstream from controlled supply systems. One exception to this logic is when certain operations within a routing are outsourced. This precedence constraint is nevertheless assumed here.

To verify that there are no other fundamental configurations regarding these constraints, a simple analysis can be performed. To begin with, it is assumed that there is always the possibility of having uncontrolled forecast-driven activities which corresponds to purchasing materials to forecast. This means that the configurations of the leftmost column of Table 2 are valid (uncontrolled forecast-driven). Configurations MTS and ATO in Table 2 both involve a forecast-driven supply system that also is controlled. This means that there can be no uncontrolled customer-order-driven activities without invalidating any of the precedence rules. The only option available is thus to include or exclude controlled customer-order-driven activities, which results in MTS and ATO. If there are no controlled forecast-driven activities, as in configurations MTO and PMTO, that is only possible with two different configurations. Either all customer-order-driven activities are controlled (MTO) or parts of them are uncontrolled (PMTO). If all activities were uncontrolled, the investigated system would be empty and here considered as void.

These four configurations of logistics supply systems highlight the structural importance of the two types of decoupling points: CODP and PODP. Based on this insight, we return to the complete set of DPs to introduce a classification that takes this insight as a point of departure.

### 4. Process-based inventory classification using decoupling points

Inventory classification is usually based on some properties of the items in inventory such as value, weight, or perishability. In the case of classification based on, e.g. withdrawal frequency or supplier characteristics, more emphasis is placed on a process perspective but one of the most important properties of processes is still not considered. As processes represent all the value-adding and non-value-adding activities performed in an enterprise, a key factor is how and why these processes are initiated, i.e. what triggers a process. In the analysis of the logistics system above, two important triggers were identified. Basically, the triggers can be characterized as exogenous or endogenous. An exogenous trigger refers to external influence, of which the customer order is the most

<table>
<thead>
<tr>
<th>Config.</th>
<th>Uncontrolled forecast-driven</th>
<th>Controlled forecast-driven</th>
<th>Uncontrolled customer-order-driven</th>
<th>Controlled customer-order-driven</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTS</td>
<td>X</td>
<td>X</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>ATO</td>
<td>X</td>
<td>X</td>
<td>–</td>
<td>X</td>
</tr>
<tr>
<td>MTO</td>
<td>X</td>
<td>–</td>
<td>–</td>
<td>X</td>
</tr>
<tr>
<td>PMTO</td>
<td>X</td>
<td>–</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
important, and an endogenous trigger refers to internal influence, corresponding to DD and DS. Finally, a process is also vulnerable when it crosses organizational boundaries, and the relation to external suppliers is of particular interest since it is a consequence of a make/buy decision and represents the reach of what is within process control of the business. In all, there are four process-based concepts that can be used in classifying the DPs and hence inventory. They are related to dependent or independent, which can be combined with a supply or demand perspective in four different ways. These four concepts (dependent, independent, demand, and supply) are combined below and then classified as strategic (related to the choice of delivery strategy and level of outsourcing) or tactical (related to other item-based DPs of importance when synchronizing the material flows).

4.1. Strategic process-based decoupling points

The customer order triggers the processes in the customer-order-driven supply system. From an inventory perspective, the DP of outstanding importance is the CODP which is subject to ID and crucial to the service level that can be achieved. The CODP can be seen as the incarnation of the delivery strategy since the position of the CODP is based on the delivery lead time. The positioning of the CODP has been identified as a key strategic decision, for example, in terms of the CODP itself (Olhager, 2003), as a consequence of balancing efficiency and responsiveness (Chopra & Meindl, 2007), as the point where lean meets agile (leagility) (Mason-Jones, Naylor, & Towill, 2000), or where the physical and innovative parts of the supply chain meet (Olhager, Selldin, & Wikner, 2006).

The positioning of the PODP is also strategic in the sense that it represents the selected level of vertical integration, i.e. the level of outsourcing. It is also crucial for buffering external disturbances and hence for providing the internal flows with the best possible conditions. From an inventory perspective, a second important property of the PODP is the amount of control that can be exercised on a process, and it is assumed that uncontrolled subsystems constitute a risk and may have a negative impact on the controlled supply system, which is downstream from the PODP.

The inventory at the CODP enables the forecast-driven supply system to focus on efficiency since the inventory at the CODP buffers against seasonal variations as well as short-term fluctuations related to demand. The dimensioning of the CODP inventory is usually quantity based, as it is the impact of the demand variations on the service level that is in focus. At the PODP, on the other hand, the situation is more concerned with the reliability of the supply lead times and hence one is more inclined to use safety lead time at this DP. In addition, the PODP also handles the lot-size inventory due to the delivery frequency from the external suppliers.

In summary, the strategic DPs are either driven by downstream exogenous factors (related to external customers through customer orders) or driven by upstream exogenous factors (related to external suppliers through purchase orders). The strategic DPs

<table>
<thead>
<tr>
<th></th>
<th>No independent demand (NID)</th>
<th>Independent demand (ID)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No independent supply (NIS)</td>
<td>–</td>
<td>NIS–ID</td>
</tr>
<tr>
<td>Independent supply (IS)</td>
<td>IS–NID</td>
<td>IS–ID</td>
</tr>
</tbody>
</table>

Table 3. Strategic process-based decoupling points.
are categorized in Table 3 based on how they are related to these two types of exogenous triggers. If the trigger is only related to ID with no independent supply (NIS), the decoupling point is of the type NIS–ID, better known as CODP (see Figure 1). The reverse, IS but no independent demand (NID), is indicated as IS–NID and defined above as PODP (see Figure 2). These two types of strategic DPs may be separate but still present in the same flow as shown in Figures 4, 6, and 7. However, in some particular cases, a strategic DP can be exposed to both independent supply and independent demand (IS–ID), which represents the case where a DP is both a CODP and a PODP (see Figure 5). The fourth case finally, with NIS and NID, is not included in terms of strategic DPs but will be further analysed next at the tactical level.

4.2. Tactical process-based decoupling points

Tactical decisions should follow as a consequence of the decided strategy. In the same way the positioning of DD and DS is a direct consequence of ID and/or IS. The strategic DPs create a structural framework based on the delivery strategy and the outsourcing strategy. The objective of the positioning of DD and DS DPs is to support this strategy. These DPs are endogenously triggered to support the ID of all related items using the bill-of-material/distribution as the road map. In all, three DP classes can be identified at the tactical level as shown in Table 4. DPs with no dependent supply (NDS) but with DD, i.e. type NDS–DD, are backward scheduled based on the demand downstream, and DPs with DS but no dependent demand (NDD), i.e. type DS–NDD, are forward scheduled based on the supply upstream. Since backward and forward scheduling in practice are difficult to combine at the same DP, the combination of dependent supply and dependent demand (DS–DD) is rarely established. An example could however be when one item is part of two different products one of which is made to customer order and the other is sold from finished goods, i.e. a hybrid of MTS (see Figure 4) and MTO (see Figure 5) for that particular item. The combination involving no dependent supply and no dependent demand (NDS–NDD) is not included at the tactical level since a tactical driver is not present. DPs classified as tactical are generally used during the planning phase to establish the appropriate level of inventory over time at these decoupling points.

4.3. Summary of process-based inventory classifications

Three types of DPs were identified above as strategic and related to ID (CODP-based) and IS (PODP-based). If NID and NIS were present (upper left cell of Table 3), the DPs would be classified as tactical and could still be differentiated as exposed to DD or DS as in Table 4. In total, these two tables highlight six different types of DPs. By combining these two tables, two of the strategic DPs, IS–NID and NIS–ID, may be further differentiated. Compared to Table 3, NID is differentiated into no demand (ND) and DD. If there is NID there could still be DD. NIS is differentiated into no supply

<table>
<thead>
<tr>
<th>No dependent demand (NDD)</th>
<th>Dependent demand (DD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No dependent supply (NDS)</td>
<td>–</td>
</tr>
<tr>
<td>Dependent supply (DS)</td>
<td>DS–NDD</td>
</tr>
</tbody>
</table>

NDS–DD

(DS–DD)
Table 5. Process-based inventory classifications.

<table>
<thead>
<tr>
<th></th>
<th>No demand (ND)</th>
<th>Dependent demand (DD)</th>
<th>Independent demand (ID)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No supply (NS)</td>
<td></td>
<td>NS–DD</td>
<td>NS–ID</td>
</tr>
<tr>
<td>Dependent supply</td>
<td>DS–ND</td>
<td></td>
<td>DS–ID</td>
</tr>
<tr>
<td>(forward scheduled)</td>
<td></td>
<td>NS–DD</td>
<td>IS–ID</td>
</tr>
<tr>
<td>Independent supply (IS)</td>
<td></td>
<td>IS–DD</td>
<td>IS–ID</td>
</tr>
<tr>
<td>(PODP based)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(NS) and DS in a corresponding way as in Table 5. This results in five different types of strategic DPs, as highlighted in Table 5. In combination with the three types of DPs in Table 4, there are in total eight types of DPs (inventory) that have been identified using the process-based approach suggested here, with a foundation in planning and control. Five of them are of a strategic character involving either IS or ID. Three classes of DPs are of a tactical character involving NIS and NID as summarized in Table 5. Table 5 is a combination of Table 3 (mainly represented by the white area) and Table 4 (represented by the shaded area). ‘No Demand (ND)’ in Table 5 represents that the use of inventory in the DP is not directly driven by demand. Correspondingly, ‘No Supply (NS)’ refers to the fact that the replenishment of the DP is not driven by supply pushing items into the DP. A DP with a combination of ND and NS would be completely disconnected from the system and is therefore not classified in Table 5.

In essence, Table 5 represents eight (nine) classes of decoupling points, i.e. inventory points. Hence, the table constitutes a classification of inventory based on the intersection between the demand perspective (the columns) and the supply perspective (the rows). Note that these DPs are tactical or strategic meaning that all DPs are related to items. From this perspective, Table 5 can be seen as providing eight different boxes where all items in an enterprise can be allocated to at least one box. In some cases, one individual item can be related to two boxes if it, for example, is used in two different end products where one is MTS and the other is MTO. It is important to note that Table 5 does not provide any information on if an item is forecast-driven or customer-order-driven, except for the CODP items which are forecast-driven since they are expected to be in stock when the customer order arrives. The table does not provide a set of possible systems but rather the building blocks that can be used for designing any type of system. The NS–ND category should be empty since all items are either driven by demand or supply.

5. Managerial implications

The eight different classes of DPs in Table 5 represent an abstraction in the sense that these are the DPs that should be handled at a strategic and at a tactical level. They also represent an aggregation in the sense that each cell in Table 5 represents a type, or group, of DPs that have certain prerequisites concerning, for example, planning and control. Using the terminology of the ABC classification (see, e.g. Vollmann et al., 2005), the process-based classification in Table 5 can be summarized as generating three classes of inventory (DPs) to focus on. Class A is considered as the most important class and is fundamental for the order fulfilment process. Class B is the second in rank...
and relates to exogenous uncertainty that is difficult to control, and Class C, finally, is of least importance since it is within the controlled system:

- Class A: CODP inventory (column 3 in Table 5), since it is key to the delivery strategy chosen and a foundation for the delivery reliability to the customer.
- Class B: PODP inventory (row 3 in Table 5), since it is key to the sourcing strategy chosen and based on the delivery reliability of the suppliers.
- Class C: Tactical DPs (grey cells in Table 5), as they represent the link between PODPs, CODPs, and the customers.

Interpreting the different types of DPs in terms of planning and control methods provides some further insights into the significance of the eight types of DPs. The details of this mapping are not the subject of this paper but some guidelines have already been outlined above and some further insights are summarized below.

The framework suggested above and summarized in Table 5 provides a baseline for materials management but does not in itself provide any methods for planning and control. It does, however, highlight some key properties of when a particular planning and control method is appropriate. A key aspect of the framework is process triggering; in materials management this aspect has received considerable interest and in general a process is assumed to be triggered in basically two ways (Hopp & Spearman, 2000, p. 340):

- A customer to the process demands that the process should be performed (frequently referred to as pull). The customer can either be an external customer or an internal customer represented by another process or a point of inventory.
- A schedule demands that the process should be performed (frequently referred to as push). In some instances it is assumed that the schedule in push is based on forecasted demand (see, e.g. Marchwinski, Shook, & Schroeder, 2008), but this is a confusing and misleading assumption in this context. How should, for example, customer-order-driven manufacturing using scheduling software be classified under this assumption? The key issue here is rather that the mode is proactive and the schedule can be based on a wide range of information, whereas the pull approach operates in a reactive mode.

The terminology used in these two cases is somewhat different but still from a functional view they are perfectly in line with the framework introduced here, to which process triggering is central. To provide further support for this conclusion, three examples are presented of what kind of scenarios three different approaches are designed to handle. First, the standard MRPII approach is discussed, followed by takt-based planning and control, and finally an example from the process industry is presented.

The DPs NS–DD and NS–ID correspond to Orlicky’s (1975) framework for MRP, where NS–ID is referred to as ID and should be master scheduled, whereas NS–DD is referred to as DD and should be handled by the MRP logic. In case there is NDD (only single-level bill-of-materials), the NS–ID could be managed using traditional inventory control methods such as an order point system. Another example is the classical ATO scenario where the order promising process considers stock availability of modules (NS–ID) at the CODP and the order promising logic checks availability downstream using forward scheduling (DS–ND) to determine possible delivery dates.
In the lean environment, the interpretation of Table 5 requires a distinction between how the system is dimensioned during planning (takt time analysis, line balancing, estimation of number of kanbans, and size of FIFO buffers, etc. (see, e.g. Duggan, 2013) and how it actually works within those boundaries during execution. The pacemaker is frequently positioned at the CODP (see, e.g. Rother & Shook, 2003). Downstream from the pacemaker, the DPs would then be considered as DS–ND and upstream as NS–DD during the planning phase. During the execution phase, all DPs would act as NS–ID responding to pull signals from downstream processes considered basically as ID.

In some process industries, the incoming raw material is not controllable but rather a consequence of long-term contracts, such as in farming. The livestock may be supplied to the abattoir at a certain age and must be processed without delay and therefore represents IS–ND and requires a planning and control approach based on divergent product profiles. Referring to process flow scheduling (Taylor & Bolander, 1994), the DPs covered by reverse flow scheduling (referred to as backward scheduled here) would be NS–DD except for the final stage, which would be NS–ID. Forward flow scheduling (forward scheduled) would be DS–ND except for the first stage, which would be IS–ND or NS–ID depending on whether demand or supply drives the flow. Mixed flow scheduling finally would then be a combination with some central point in the flow being NS–ID and then upstream NS–DD and downstream DS–ND.

These examples highlight how inventory can be classified and related to different scheduling and control techniques. As can be seen from these examples, the approach for the operational DPs here follows from the approach selected for the corresponding item DP (which is not generally necessary if control can be differentiated on an operations level). This means that if the item DPs are of the type NS–DD, then also all the operations to produce that item are assumed to be DD (backward scheduled).

As shown above, the classification framework introduced can be used in a contextual way for a wide range of environments to classify different types of DPs. The approach is hence generic and not only applicable in certain environments. The approach rests on a set of fundamental system properties and can therefore be applied in most environments.

6. Conclusions and further research

Materials management is a comprehensive topic usually involving several thousands of items and a multitude of aspects to analyse such as risk, investment, durability, etc. Using abstraction and aggregation as outlined in this paper, the management of inventory can be more explicitly targeted at focusing on the inventory of strategic importance, i.e. the strategic DPs. Process-based classification enables evaluation of inventory management across different delivery strategies (different positions of the CODP), which are of particular interest to companies with hybrid strategies where, for example, both MTO and MTS products are present. From a customer service perspective the management of the CODP inventory is critical to all kinds of delivery strategies. In combination with evaluation of how the inventory at the PODP is managed, a comprehensive view of management of strategic inventory can be obtained. The CODP is also the key starting point for most planning and control methods for manufacturing and logistics. The framework does not in itself provide a new approach to materials management but it provides a structured way to better understand the role of different DPs, i.e. inventory points, and their role in materials management.
With this classification as a point of reference, there are many possible lines of research to pursue. One of the most important is probably that this classification may guide researchers on inventory and materials management in terms of which DPs to focus on. Also, in case of evaluation of manufacturing strategies across different delivery strategies, the strategic DPs may serve as a point of reference for delineation between lean and agility (see, e.g. Mason-Jones et al., 2000). Giesberts and van der Tang (1992) pointed out that in many cases companies have ‘hybrid production situations’ and they showed how information systems may take this into account. The impact of this classification scheme on hybrid strategies remains an area of interesting opportunities for further research that could also take the framework suggested by Wikner (2014) into consideration. In the same spirit, the practitioners can use this classification to focus their investment on inventory and materials management where it gives the best leverage. The classification may also work as a tool for categorizing different concepts such as planning and control methods to provide guidelines on how to implement these methods based on strategic as well as tactical decoupling points.

Acknowledgements
This research has been performed in collaboration with six companies in the projects KOPeration and KOPtimera.

Disclosure statement
No potential conflict of interest was reported by the authors.

Funding
The research has been funded by the Swedish Knowledge Foundation (KKS), Jönköping University and the participating companies.

ORCID
Joakim Wikner http://orcid.org/0000-0003-2252-5337
Eva Johansson http://orcid.org/0000-0003-3783-0633

References


