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An ontology for flow thinking based on decoupling points – unravelling a control logic for lean thinking

Joakim Wikner

Abstract

Continuous flow is the guiding star for lean thinking and considered the ideal state for value streams. Despite this objective, it is seldom possible to obtain a state of continuous flow in a wider context. Decision makers face dynamic environments, and variable internal preconditions require a flow-thinking approach that provides support in response to these challenges. In the present study, the underlying logic of flow thinking is first identified as the key management layer, and thereafter the effectiveness of flow is targeted. The vision of continuous flow is challenged by different exogenous requirements that result in flow discontinuities. Flow thinking is then used to identify 10 decision categories based on these discontinuities, each related to a type of decoupling point and classified as time-based (exogenous) or conversion-based (endogenous). The flow-thinking approach is finally applied in three different contexts: a time-phased product structure, a modularized approach for planning and control, and a mixed-model value stream.

1. Introduction

Shifting their focus from functions to flow is a challenge for most managers as the competitive significance of time continues to gain significance (de Treville et al., 2014). Many managers have turned to lean thinking for advice, but although flow is a core theme of lean thinking in terms of, for example, value stream analysis (see, e.g. Rother & Shook, 1998), the details provided by lean thinking on how to approach flow have emphasized efficient execution rather than effective control. Lean was originally outlined as a system based on a process perspective in pursuit of customer value. Womack and Jones (1996) summarized these insights in their famed five steps of lean thinking, which illustrate the connection between customer value and continuous improvement via the logic of flow. The value stream is the foundation for analysis in lean thinking, and it provides some fundamental insights on the characteristics and value-adding activities of flow.

Thus, flow is an important element of lean thinking, but even outside this domain, interest in flow is significant. From a more general perspective, Schmenner (2001) emphasized the significance of swift and even flow for operations management.
Despite these generic claims, the actual control points of a particular flow are not highlighted in terms of either swiftness or evenness in the value stream analysis, where the emphasis is on the value-adding per se rather than a holistic view of how the value-adding is controlled. The actual initiation of flow is fundamental to flow control, as it triggers the activities of value streams. The flow trigger in lean thinking is based on the famed ‘pull signals’, but details of the interaction between different entities in the flow, such as resources and activities, are lacking, and differentiation based on customer and involvement of different actors such as suppliers are similarly not well accounted for (see, e.g. Andrew & Nicholas, 2006). Despite these deficiencies in terms of understanding the control points, value-stream analysis has shown potential in numerous practical applications and has become a de facto standard for flow analysis. The application of value-stream analysis has reduced waste and increased cost efficiency as key capabilities. But to actually tap into the potential of these value streams, the next step should be to put more emphasis on flow control targeting different consistent parts of the flow that may be decoupled to enable more focused and effective control. Such an approach would widen the scope of value-stream analysis to provide strong support for not only cost efficiency but also differentiation as competitive advantages.

Improving the support for effective control represent the foundation for this paper. More specifically, the purpose is to develop an ontology for flow thinking based on decoupling points, which is used to unravel a control logic that can be applied to lean thinking and value-stream analysis as well as other contexts to support not only cost efficiency but also competitiveness based on effective differentiation strategies. The value-creating flow is the outcome of numerous decisions, such as what resources to use and what activities to perform. While the volume of such decisions is obviously vast, the literature has demonstrated that categorizing decisions makes the decision problem manageable and the development of decision support viable (see, e.g. Hayes & Wheelwright, 1984). The flow logic should thus have a solid foundation in decision support if it is to be operational and establish effectiveness as well as efficiency, which is the foundation of management (Drucker, 1966).

This paper is organized into six sections, including the motivations outlined above. Section 2 covers the background to the flow-thinking ontology, providing information on how the ontology was developed. Section 3 provides a theoretical framework including a brief literature review of the previous work on which the ontology is based. In Section 4, the flow-thinking ontology is defined and developed in two stages; the first stage focuses on developing five decision categories that are more axiomatic, while the second stage considers five more ‘pragmatic’ decision categories. The section ends with a summary of the 10 decision categories, which together constitute the core of the flow-thinking ontology. Section 5 illustrates potential applications of the ontology and provides insight into some of the benefits of the approach. Section 6 concludes the paper with a summary of the results and some suggestions on avenues for further research.

2. Research approach

This research is fundamentally based on logical concept development to establish a theoretical model to guide flow analysis. A theory should, according to Wacker (1998, pp. 363–364), ‘carefully outline the precise definitions in a specific domain to explain
why and how the relationships are logically tied so that the theory gives specific predictions. The domain considered here concerns flow, and in particular, it concerns decision-making in relation to flow; decision-making is therefore the baseline for the following definitions. The theory of flow thinking as such represents a systems approach in which the flow is central; all the constituent parts of the system are thus identified from a flow perspective. From a flow perspective, the ideal state for efficiency is a continuous and level flow (Womack & Jones, 1996). However, the preconditions for flow vary in terms of demand and supply, which presents challenges to the effectiveness of flow. These variations imply that a level, continuous flow may be suboptimal from a business perspective, as they leave room for discontinuities in the flow. A theory on this topic is the point of departure for this research and the research is based on the varying requirements on combining effectiveness with efficiency in decision-making.

The logic of flow thinking as outlined here considers the content rather than the process and is based on the terminology used by e.g. Hayes and Wheelwright (1984). Content refers to the constructs defined in the theory, such as decoupling points, and the focus is placed here rather than on a systematic approach in terms of process, i.e. how these constructs should be used. Developing such content is basically about developing theory and, as Mintzberg (2005) states, ‘Theory development is really about discovering patterns…’; the patterns here are related to flow. Thus, a systems approach based on flows is first employed, and then the main characteristics of the flow are logically deducted from the perspective of such a system. Based on fundamental axiomatic assumptions, a set of five discontinuities is initially identified as a foundation of the theory. These exogenously implied discontinuities are then complemented with an additional five decision categories based on conversions, i.e. transformations, performed in the flow. This second set of decision categories is approached from a conversion logic perspective rather than an axiomatic perspective. In summary, the complete set of 10 decision categories is based on discontinuities and their implications for decision-making is derived via logical reasoning even though the point of departure is somewhat different for the two types of discontinuities.

The content, i.e. the developed theory, is subsequently formulated as an ontology to emphasize its structural meaning. According to the literature, ontology basically has two meanings. In relation to the philosophy of science, ontology concerns the systematic account of existence, but this is not the intended use of the term here. Rather, inspiration comes from knowledge management and related areas, such as artificial intelligence, where the concept of ontology refers to information structures: ‘An ontology is an explicit specification of a conceptualization’ (Gruber, 1993, p. 199). An ontology therefore represents the logic of conceptual models: ‘A conceptual model is an actual implementation of an ontology’ (Welty & Guarino, 2001, p. 52). The derivation of the ontology for flow thinking therefore considers fundamental properties of flows and through deduction and logical reasoning derives constructs of the theory. However, most of the constructs have been applied previously in various industrial applications, thereby proving their empirical relevance in different contexts (see, e.g. Bäckstrand, 2012; Wikner & Bäckstrand, 2018; Wikner & Noroozi, 2016; Yang, Yang, & Williams, 2010). The intention here is thus not to develop entirely new constructs but to provide an integrated foundation for previously developed constructs. Additionally, the complementary properties of the concepts are highlighted; Table 5, near the end of this paper, provides an overview of the discontinuities concerned.
3. Theoretical framework

The theoretical framework first utilizes general systems as a foundation for flow thinking and then introduces key areas necessary to outline the ontology for flow thinking. The systems approach is introduced, with emphasis on the system concepts of exogenous and endogenous, followed by three system perspectives. Next, systems are considered from a flow structure perspective and the concept of decoupling point (DP) is introduced and positioned as a decision-based concept. Thereafter, the strategic lead times used for exogenous decision categories are defined. Finally, conversion, i.e. transformation, is introduced as the foundation for the endogenous decision categories.

As shown in Figure 1, flow thinking is based on four cornerstones: system and structure constitute the foundation of flow thinking, while time and conversion are the baselines for deriving the decision categories. These four cornerstones are outlined next.

![Figure 1. The four cornerstones of flow thinking.](image)

3.1. Systems approach

A systems approach is applied when something being analysed is considered as an integrated entity with clearly demarcated boundaries in terms of context. Such system thinking is available in many shapes and for different purposes (Jackson, 2003). A system is generally considered to be dynamic, i.e. something changing over time, and consequently, the system has states that change over time. Lean thinking is a systems approach embodied, as mentioned above, in the concept of value stream, and the focus on improvement is related to the dynamic state. A value stream is a self-contained entity within lean thinking in that it ideally represents a complete flow from suppliers to customers and includes all the resources necessary to that flow. In this sense, a value stream is a complete system with interfaces to customers and suppliers of the value stream, and processes are performed in this system based on different triggers. Triggers of actions in the system can be referred to as exogenous – caused by factors outside the system (such as a customer requirement) – and endogenous – caused by factors inside the system (such as planning initiatives or pull signals). These two key concepts in flow thinking can be used for classification of decision categories.

An enterprise system can be very complex, with many different aspects that must be considered when managing such a system. Enterprise refers here to a generic industrial system, whereas e.g. company more specifically refers to an entity that is engaged in business
and hence is directly associated with a financial system. Such abstraction is a useful approach for considering significant properties from specific perspectives. Lean thinking and lean accounting (Maskell, Baggaley, & Grasso, 2011) are thus based on the three perspectives of enterprise, value stream, and cells for performance management. Lean emphasizes flow as a fundamental property, and creating continuous flow is a clear objective, as it supports repetitiveness, which is the foundation for continuous improvement. Taking flow as a point of departure shifts the focus from the performance of the system to the operational management of the system. Henry Ford once stated, ‘if a man did his work well […] the profits and all financial matters, would care for themselves’ (Ford & Crowther, 1922, p. 44), which is in the spirit of flow thinking.

When analysing flows, three different types of abstraction from a system perspective provide important information, as illustrated in Figure 2. For company management, the legal perspective is important as it provides information about the financial performance of the enterprise and relates to the sponsor of the transformation performed in the enterprise. The concept of sponsor refers here to the entity funding a transformation and in this sense owns or hires the resources involved. The different entities at the company level are each referred to as actor entities, and these actor entities have business relations with other actors. Financial performance of an enterprise is a consequence of all the physical transactions taking place in the enterprise. This is the responsibility of supply chain and operations (SCO) management, which focuses on physical transformations such as manufacturing, distribution, transportation, etc. Entities at this level are dominated by a certain type of transformation and are hence referred to as value-add entities. From this perspective, manufacturing mainly concerns transformation of physical form (making things), transportation mainly concerns transformation of place (moving things), and warehousing mainly concerns transformation of time (storing things).

Still, there is a more general platform that may be used for flow management, and this is here referred to as the logical perspective, which is transformation focused, in line with Moeller (2008). The logical perspective avoids focusing on the type of transformation being performed and instead emphasizes more general aspects of flow, such as what drives the flow, who controls the flow, and the differentiation of the flow. This in turn is based on a ‘meta-level’ of process management that covers the fundamental constructs. This is a core component of the flow-thinking ontology and the foundation for the categorization of DPs. The distinction between different perspectives can be illustrated by so-called vendor-managed inventory (VMI) systems in which

| System perspective | Transformation association | Management approach |
|--------------------|---------------------------|---------------------|
| Legal perspective  | Sponsor of transf. (actor)| Company management  |
| Physical perspective| Type of transform. (value-add)| Supply chain and operations (SCO) management |
| Logical perspective | Transformation (control) | Process management |

Figure 2. Flow thinking and the three types of perspectives (based on Wikner, 2014a).
distinctions should be made in terms of who owns the inventory (e.g. consignment), where the inventory is physically based (e.g. at the site consuming the parts), and the control logic applied (e.g. min-max system). Hence, a VMI solution should be defined in terms of legal perspective (owner), physical perspective (site location), and logical perspective (control logic). For each perspective, the flow can be characterized as related to a number of entities and they are related to the abstraction level and here referred to as legal entity (LeE), physical entity (PhE), and logical entity (LoE).

The enterprise context is becoming increasingly connected as information technology continues to enable rapid exchange of ever more vast amounts of data. Systems are therefore not independent of their environment. However, irrespective of the system perspective employed, an enterprise system should be analysed as an open system (Checkland, 1981) of connected entities. Connections with the environment are typically complex, and therefore the simplest structure that is usually considered relevant in relation to flows is a triad (Mentzer et al., 2001) of three entities, the focal entity, a downstream requesting entity, and an upstream partner entity. Three different types of triads can be identified, as shown in Figure 3, based on the three system perspectives of Figure 2 and the corresponding types of entities.

The legal triad, at the top of the figure, is at the company level and basically represents a supply chain from a financial perspective, where the focal actor has a customer and a supplier. The term actor is included in each name to emphasize the absoluteness of the reference. For example, the shorter term ‘customer’ is relative in that the focal actor is the ‘customer’ of the supplier actor and the customer actor is the ‘customer’ of the focal actor. The physical triad is probably the most commonly used in the SCO context, where each entity corresponds to for example a geographical site or transportation between sites. These top two triads in Figure 2 are commonly used, but they provide only a fragmented view of the information required for effectively managing flow. Thus, a logical level is defined from a control perspective, shown at the bottom of the figure, and this is the foundation for the subsequent identification of decision categories which rests on the foundation of flow structures.

Figure 3. Triad of entities for the three different system perspectives.
3.2. Systems and flow structures

The logical system perspective consists of a network of LoEs where each LoE represents a context where control can be applied in a holistic and integrated fashion. The actual complexity of the LoE can be described as a flow structure made up of a network of segments. The core component of the flow structure is a segment – which is referred to herein as atomic, in the sense of irreducible; segments are illustrated in Figure 4 by a line segment with a solid circle at both ends, which indicate the starting and ending points of the atomic segment. An atomic segment basically connects two states, corresponding to the circles at the end points of the line, where the line itself represents some type of transformation that is performed to change something from the initial state (start node) to the final state (end node). The transformation is atomic in the sense that the transformation is either performed in its entirety or not performed at all, i.e. there are no intermediate states on the line segment. Figure 4 illustrates the four fundamental ways of combining atomic segments into a composite flow. The most basic flow structure is two segments occurring in sequence (X1 followed by Y1). The next stage is the combination of three atomic segments in a diverging (X2 followed by Y2 and Z2) or converging (X3 and U3 followed by Y3) flow. These scenarios may involve more than two joining (converging) segments or more than two splitting (diverging) segments, but the fundamental properties are the same as for the cases illustrated in Figure 4. Finally, a flow can be a combination of converging and diverging atomic segments. Converging flows are frequent in discrete manufacturing involving assembly but could also represent, e.g. packaging, where packaging materials are combined with the contents of the package. Diverging flows are usually associated with process industries in which one raw material is processed into multiple products (two different products at the same place), but it can also represent distribution scenarios, such as moving products from a central warehouse to multiple local warehouses (one type of product in two different places).

The atomic segments can be combined into more complex structures, such as that shown in Figure 5. At this stage, the time dimension is not included, so all segments have the same horizontal extension (length) in the figure. However, the segments are drawn horizontally to prepare for the introduction of a horizontal time axis. The vertical extensions between e.g. X and Y are hence insignificant in Figure 5. A downstream LoE (Post Control, PostCtrl) controls segment Z and two different upstream LoEs (Pre Control, PreCtrl1 and PreCtrl2) control segments V and Q. The rest of the segments are in the central LoE (Focal Control,

![Figure 4. Four fundamental flow configurations.](image-url)
FocalCtrl) Note that in this case, the final customer is not included, as PostCtrl refers to the LoE providing item Z. If the final customer were included, a fifth LoE would be added downstream of the PostCtrl entity in Figure 5.

Sequentially placed segments may be strictly dependent, i.e. coupled, or they may be independent to varying degrees; this is here referred to as decoupling. Decoupling is a general concept defined by APICS in Blackstone (Blackstone, 2013) as ‘Creating independence between supply and use of material. Commonly denotes providing inventory between operations so that fluctuations in the production rate of the supplying operation do not constrain production or use rates of the next operation’. As indicated here, decoupling is usually associated with a DP of inventory positioned between two stages of the flow. Blackstone (2013) defines DPs as ‘The locations in the product structure or distribution network where inventory is placed to create independence between processes or entities. Selection of decoupling points is a strategic decision that determines customer lead times and inventory investment’. Obviously, decoupling is here associated with material flows, as the concept of inventory is included, but at the same time, general process terminology is used, indicating that the concept has wider applications. Using a materials-based approach, DPs can be differentiated into three categories (Wikner & Johansson, 2015). The first category is interoperation DPs, most well known as queues in front of resources. The second category is item DPs, which are important in the sense that material in a particular state has been given a unique identifier, usually referred to as an item number or part number. Introducing this identity code enables item-level management of materials. The third category is strategic DPs, which are related to identification of processes in an enterprise-wide context, i.e. processes that are of strategic significance for the enterprise and therefore usually related to customers or suppliers.

- **Interoperation DPs**, which separate different activities to be performed;
- **Item DPs**, which identify the results of different groups of activities (referred to as sub-processes) that are performed as a whole once initiated; and
- **Strategic DPs**, which are related to identification of processes in an enterprise-wide context, i.e. processes that are of strategic significance for the enterprise and therefore usually related to customers or suppliers.
This generalization of the concepts enables a more generic interpretation of flow thinking and DPs. Table 1 provides a summary of the analogous SCO-based and process-based terminology and addresses the levels introduced above in relation to DPs. In addition to the levels introduced above, the top-level system is added and it is noted that a single activity can be subdivided into a number of steps, or actions, corresponding to individual tasks. The process level does not have a straightforward analogy in SCO management, but based on the ontology for flow thinking, the process level will be further outlined and subsequently information will be provided on the attributes of the corresponding concepts in SCO management. Process management is focused on transformation at all levels whereas for SCO management this is the case only for levels 4 and 5. For SCO management levels 1 and 3, the emphasis is instead on the output from the transformation. A process-based approach to decoupling generalizes the concept of DP and places more emphasis on the actual decisions being made. A more general definition would thus be a point that ‘separates decisions that are made under different consistent properties related to a specific decision criterion’ (Wikner, 2014a, p. 176). In some cases, the distinction between the upstream properties and the downstream properties in relation to a DP is not obvious, and a mix of properties may be valid for a section of the flow. This mix, or hybrid, is referred to as a decoupling zone (DZ) (Wikner & Rudberg, 2005), and as shown by Wikner (2014a), a DZ can be either process-based – a smooth transition between properties along a flow – or resource-based – a consequence of aggregation of more than one flow being performed by a resource.

Flow thinking is concerned in particular with strategic DPs, which impact different enterprises in such fundamental ways that the concept can be considered industry-generic. From an industry-generic perspective, the decoupling approach is a core component of strategic concepts such as postponement (van Hoek, 1997) and legality (Naylor, Naim, & Berry, 1999), but it is also applicable to a much wider set of supply chain strategies (see, e.g. Wikner, 2014b). Strategic DPs may be positioned for different purposes, but in many cases they are positioned based on the same conditions, using what is frequently referred to as strategic lead times (Wikner, 2014a). Based on the flow structure outlined above, the next logical step is to expand on the two aspects of time (when to perform a segment and how long the segment is) and thereafter conversion (how to perform a segment).

### 3.3. Flow structures and time

Flow structures by definition represent a transformation’s overall pattern but lack the timing information typical for individual instances of the definition. Time should therefore be added to the definition to provide a more comprehensive picture of the flow logic, and this is represented by a time-perspective (TP). In most contexts, time is a critical finite resource and time not used is lost and cannot be recovered, or as

| Table 1. Analogous terminology between SCO management and process management. |
|---------------------------------------------------------------|
| SCO management    | Process management |
| Level 1           | Product structure  | System |
| Level 2           | –                  | Process |
| Level 3           | Item               | Sub-process |
| Level 4           | Operation          | Activity |
| Level 5           | Task               | Step or Action |
Benjamin Franklin (2004) once put it: ‘lost time is never found again’. Also, time is an important aspect of provisioning of value-add, for example embodied by the time line in value stream analysis (see, e.g. Hines et al., 1998). Time is therefore a fundamental aspect of flow management and should be at the core of the ontology for flow thinking.

Figures 4 and 5 illustrate flow patterns where no time perspective is included. Extending each atomic segment to the expected length of the time it takes to perform the segment results in a time-phased flow structure. This type of time-phasing carries many similarities to materials planning with infinite capacity (see, e.g. Clark, 1979) but has no explicit concern for the finiteness of resources such as is included in Gantt charts. For illustrative purposes, each segment will be positioned horizontally and parallel with a time line, as shown in Figure 6, where $L_i$ represents the number of units of time it takes to perform segment $i$. Figure 6 illustrates an example based on Wikner (2014a) with a converging flow. In this example from materials management, the flow structure is based on materials; items are atomic segments and the corresponding product structure is shown to the left in the figure. Note, however, that each segment also could, with a different abstraction level of modelling, correspond to, for example, a manufacturing operation.

Figure 6 also includes a number of strategic lead times (SLTs). A SLT is a lead time that plays a significant role from a demand or a supply perspective, is based on the boundary of the system and in addition is related to the positioning of strategic DPs. Three types of SLTs are identified as a platform for flow thinking; the first type is risk based and concerns the complete network structure. The following two are based on control and variants, and consequently, these types are related to individual atomic segments.

3.3.1. Risk-based SLTs
Risk, and in particular demand-based risk, is related to the level of speculation that is required. When information about what a customer requires, for example expressed in

Figure 6. Example of strategic lead times for a time-phased flow structure (based on Wikner, 2014a).
terms of a customer order, the PostCtrl risk may be reduced and then instead of performing activities on speculation they can be performed on commitment to customer orders. The SLT delivery lead time \((D)\) corresponds to the customer’s requested delivery lead time, and the SLT system lead time \((S)\) is the cumulative lead time of the complete time-phased supply structure (see Figure 6). Hence ‘system’ here refers to the extended LoE being analysed. This means that from \(S\) to \(D\), i.e. \(S – D\) at the left of \(D\) in Figure 6, the LoEs involved ‘own’ the risk; after \(D\), the customer ‘owns’ the risk unless otherwise stated in contracts. Note that the customer is not modelled as a LoE; \(D\) is provided only as a point of reference. In case administrative time is required for dealing with the customer order, the \(D\) used here should be reduced by that administrative time. This means that the customer might have to wait more than \(D\) if administrative activities are handled outside of this model. The risk-based SLTs are further defined and illustrated later in Figure 10.

3.3.2. Control-based SLTs
All branches of the supply structure can be split into multiple parts. One is the part that can be controlled by the LoE FocalCtrl responsible for delivering to the customer; the others are not controllable and may be positioned upstream or downstream of the LoE. The controllable part is referred to in terms of SLT as Internal \((I)\) and the part beyond control is referred to as External \((E)\). Additionally, uncontrollability can exist both upstream and downstream from FocalCtrl, resulting in External Upstream \((E_{US})\) and External Downstream \((E_{DS})\). Each upstream branch has a separate tuple of \(E\) and \(I\), as shown in Figure 6. For a diverging flow structure, the downstream branches would have the corresponding tuples. Consequently, there is a unique \(S\) for each path in a more complex structure. In the example of Figure 6 there are two branches upstream and one downstream, and hence, \(S_{V,Z} = E_{US,V} + I_{V,Z} + E_{DS,Z}\) and \(S_{Q,Z} = E_{US,Q} + I_{Q,Z} + E_{DS,Z}\) and as a consequence \(S = \max\{S_{V,Z}, S_{Q,Z}\} = S_{Q,Z} = 12\) time units. The control-based SLTs are further defined and illustrated later in Figure 9.

3.3.3. Variant-based SLTs
Both demand and supply provide a basis for creating variants based on customer requirements. Other variants exist that are not directly related to the customer’s requirements, but these ‘internal’ variants are not covered here (these are related to the split/join discontinuity introduced later). From a demand perspective, the PostCtrl can request variants, and from a supply perspective, it may be possible to create a specific set of variants. The variants can be created at certain points in the supply structure corresponding to a SLT referred to as Adapt lead time \((A)\). The SLT corresponding to a point at which variants may be created is referred to as Supply-based \(A\) \((A_{S})\). Comparing the extension of all \(A_{S}\)s with \(D\), it is possible to identify the subset of \(A_{S}\) that can be used for delivery of unique, i.e. individualized, offerings. Individualized indicates that the offering is not only unique only for that particular customer, usually associated with customization, but also for that particular delivery. The point finally selected is referred to as Demand-based \(A\) \((A_{D})\); for simplicity, this is also referred to as \(A\) with no index. In the example in Figure 6, the set \(A_{S} = \{A_{S,U}, A_{S,Z}\}\), and subsequently, \(A = A_{D} = A_{S,Z}\). For SLT \(A\), it is particular important to be specific about the
time when $A$ is short, as $A = 0$ indicates that there is no time for adaptation and hence the product is standardized. An adapt lead time greater than zero, however, indicates that the product can be individualized, which in the case of for example software adaptation may be possible in a very short time, but it does require some time, and hence $A > 0$. The variant-based SLTs are further defined and illustrated later in Figure 11.

The complete set of SLTs is potentially large, given all the possible variants and different supply structures. From the discussion above, however, it is possible to identify four groups of SLTs from a time perspective that are of major importance for flow thinking, as shown by Wikner (2014a) and illustrated in Figure 7:

(1) System lead time ($S$), which may also contain lead time for segments, or subprocesses, of the PreCtrl and the PostCtrl;
(2) Delivery lead time ($D$) based on what is requested by the external customer;
(3) Internal lead time ($I$) of FocalCtrl, which is also related to the external upstream lead times ($E_{US}$) related to PreCtrls and downstream lead times ($E_{DS}$) related to PostCtrls. For each path in the structure, it is possible to identify a relationship between internal and external lead times: $E_{US,i} + E_{DS,j} = S_{ij} - I_{ij}$ (which is valid for each path from $i$ to $j$ in the flow structure); and
(4) Adapt lead time ($A$) with all variants of $A_S$ and $A_D$.

These four groups of SLTs can be used in flow design to create a balance between different characteristics of the flow. These flow characteristics are however not themselves the goal but rather represent the underlying factors for creating a profitable business. Besides these exogenous factors, the system has additional properties that are important for identifying additional strategic DPs, and this is related to a set of key conversion perspectives.

### 3.4. Flow structures and conversion

The SLTs are all related to exogenous factors of the system under study. An endogenous perspective brings other characteristics of the system into focus; in particular, conversion, i.e. transformation, perspectives are important. The first endogenous perspective is related to the boundary and the boundary’s direct impact on resources. This refers to the customers of the LoE and the services that the customers require. This conversion perspective (CP) is therefore referred to as customers and services and is focused on understanding the customers and the customer requirements and how services can be produced in close cooperation with customers. The second CP is based on the actual transformation dimension and concerns the products that are transformed, therefore
referred to as products and processes. To make the approach industry generic, it is important to investigate product categorization and the impact of these categories on the processes. The third CP is based on the execution of the transformation processes via use of resources and capacity and is labelled resources and capacity. Of particular interest here is how the available capacity resources used in the transformation process affect the continuity of the flow depending on the type of object or service being transformed. The final CP concerns the control of transformation and covers both planning and control. Planning and control concerns all aspects of flow management related to a LoE and how different methods and techniques can be adapted to flow thinking. The CPs are summarized in Figure 8.

4. The flow-thinking ontology

Flow as a concept is basically simple, as pointed out by e.g. Schmenner (2001), but still, holistic decision-making is complex because a vast array of information is available and each decision may cover several aspects of the flow. To enable a more focused approach to decision-making, a set of decision categories (DCs) can be identified, each of which is based on a specific criterion, such as the driver of the process. As shown by Wikner (2014a), a DC can be divided into different decision domains where a particular property of the decision criterion is valid. One decision domain, for example, may have forecast as the driver, while another has customer orders as the driver. These two decision domains belong to the same DC, but because the decision criterion has different properties for the different domains, the transition point of the flow between the two decision domains represents a discontinuity in the DC, which is here associated with a DP. The complete set of DCs that can be identified from a flow perspective is expected to cover most important aspects of flow and hence will represent the ontology of flow thinking where a discontinuity separates a flow into two parts, each aiming for continuous flow. Once continuous flow is achieved in the parts the discontinuities disappear and the final goal of a system wide continuous flow is realized. The management philosophy of flow thinking can therefore be defined as:

Flow thinking is a management philosophy based on a holistic and integrated approach to continuous flow and flow discontinuities.

The DCs are divided into two distinct groups based on the extent to which the DC is a derivative of the boundary of the system. Exogenous DCs (ExDCs) are defined based on the boundary and are logically and axiomatically derived from one or more SLTs. Because the definition is relative to the boundary, a flow is assumed to consist of only one discontinuity of that type, as the flow is assumed to be unidirectional with only two points of contact with the boundary. Hence, only one DP of each type can exist for a

Figure 8. The four conversion perspectives (CPs).
path in the network structure (for example, the structure in Figure 6 has two paths). If multiple DPs of one kind are identified in one flow, then the flow should be broken down into several sub-flows. Multiple flows can thereafter be aggregated from a resource perspective, as in the example illustrated later in Figure 19, where the two zones represent such resource-based aggregations. An endogenous discontinuity, in contrast, is based on internal properties of the LoE and hence the point of reference is something other than the boundary; thus, multiple endogenous based DPs of the same type can exist in the same flow within a LoE. For example, a flow may be based first on continuous objects, then on discrete objects and finally on continuous objects again. There is no general limitation given by the boundary that constrains how the objects can transition between different states. The endogenous DCs (EnDCs) are instead defined based on the CPs given in Figure 8. As a consequence, most or all of the ExDCs are of interest when applying the ontology, whereas only a subset of the EnDCs – or even a perspective not covered here – might be included.

Both sets of DCs are, however, flow based to varying extents, and hence, the properties of each DC are divided into upstream (Pre-DP) and downstream (Post-DP) properties in relation to a particular DP (see, e.g. Tables 3–5). Note that hybrids of Pre-DP and Post-DP properties exist for ExDCs, which corresponds to the decoupling zone described earlier (Wikner, 2014a). All DCs identified below and their key properties are summarized later in Table 5.

4.1. **Exogenous decision categories**

The ExDCs are fundamental in that they are basically independent of the internal function of the system as they are based on the interface with the environment, i.e. the boundary. In this sense, the ExDCs are fundamental for flow thinking and in all cases of relevance to the analysis. The ExDCs are deduced from the SLTs, which hence represent the axioms of the ExDCs.

4.1.1. **The logic behind the exogenous decision categories**

The logical perspective of Figure 2 is related to process management using generic process-related terminology, as in the right column of Table 1. The connection to the physical perspective and SCO management can be illustrated in different ways, as the logical perspective can represent several sets of entities of the physical perspective. The most obvious is material based and, as shown in Table 1, there are several obvious analogies. Most of the discussion below is related to levels 1–3 of Table 1, where levels 1 and 3 have obvious connections but level 2 is not that obvious in managing the enterprise; this also indicates an important contribution of the process-management perspective, as it highlights this less emphasized component of enterprise management.

Exogenous-based decoupling can be categorized into five types related to five questions representing the ‘logical reasoning’ in relation to the ExDCs:

1. **What are the external boundaries of a flow system?**
   Basically, identify what is included in the analysis from a lead-time perspective.
2. **What is the extension of the controllable part of a flow system?**
   The system boundaries defined on lead times may include parts beyond the LoE’s control.

3. **What is the driver of a flow?**
   When the preconditions of a flow are identified the focus shifts to initiation.

4. **How can a flow be differentiated for different flow sinks?**
   Once the driver is known, the level of uniqueness is considered.

5. **To what extent is exogenous information shared in a flow?**
   Information from outside the controlled system may be shared.

These five questions are next used as a point of departure to identify and define the ExDCs and the corresponding DPs. Each question above corresponds to one subsection below, and the ExDCs are thereafter summarized in Table 3.

### 4.1.2. External boundaries of a flow system (B1a and B1b)

The foundation in any systems approach is the boundary of the system because it defines the extension of the system. A typical example of a boundary in relation to flow thinking is the concept of ‘demarcation lines’ used by Hoekstra and Romme (1992). The first ExDC is related to identification of the system’s boundary and is labelled B1 Flow boundary (boundary of the first discontinuity type). The first variant of B1 is B1a Flow boundary sink and is the point of reference for most of the other ExDCs as it represents the end point of the flow (usually the interface with the customer). The second variant of B1 is B1b Flow boundary source, representing the upstream boundary at the starting point of the flow. The labels ‘source’ and ‘sink’ refer to the end-points of the value-adding flow through the system from source to sink. Note that ‘flow’ here represents the value-adding transformation being performed and can involve all types of transformation, including information and people as well as materials. Both these B1 variants are illustrated as grey boxes at the start and end of the flow in Figure 9, where SLT S represents the lead-time based extension of the system from a flow perspective.

The downstream B1a may be seen as the customer of the system, but to keep the discussion general, and to avoid any terminology that might lead to an actor-based view, the more general flow-based label ‘Flow sink’ is used here. The sink is the end point of the flow and hence decouples the flow from the continuation. From a systems perspective, however, it is possible that objects delivered from the flow may be returned, but this would then be handled in a separate return flow in which the ‘customer’ acts as the supplier of the returned material; thus, the value-adding flow would be from left to right in the illustrations (Wikner & Tang, 2008). The post-DP property in Table 3 is hence external and, correspondingly, the pre-DP property is internal to the system. The DP itself is represented by a blue box labelled SinkDP at the lower right of Figure 9. If the boundary is not well defined, this is indicated by the B1a-zone extending downstream from B1a.

The upstream boundary B1b is likewise the point of reference for the in Figure 9, which is positioned at the SLT S upstream from the flow sink. A return flow may exist here, as well, which would be handled in a separate flow modelled from left to right. Because B1b is the upstream boundary, the pre-DP property is external and the post-DP property is internal to the system. The DP is again represented by a blue box but labelled SourceDP at the lower left of Figure 9.
4.1.3. **Controllable part of a flow system (B2a and B2b)**

Once the system is defined, the next logical step is to identify control mechanisms. The ExDC B2 Flow controllability is crucial in that it decouples the flow into one part controlling the flow and two parts out of reach of control by the controlling part.

- The controllable part of the system is referred to as a FocalCtrl LoE (see Figure 9), because it is possible for the FocalCtrl to apply control in all parts of the FocalCtrl.
- Downstream from the FocalCtrl, the flow is under no control of the FocalCtrl; it is then referred to as the downstream uncontrollable LoE, i.e. the PostCtrl (not included in the figure). The downstream boundary of the FocalCtrl is represented by B2a Flow controllability sink, and the downstream controllability decoupling point (DCDP) indicates where the activities performed in the flow become uncontrollable.
- Upstream from the FocalCtrl, the flow is under no control of the FocalCtrl and is referred to as the upstream uncontrollable LoE, i.e. the PreCtrl (not included in the figure). The upstream boundary of the LoE is represented by B2a Flow controllability source, and the upstream controllability decoupling point (UCDP) indicates where the activities performed in the flow become controllable. This DP has also been referred to as the purchase order decoupling point (see, e.g. Wikner, 2014a) but because the definition is based on controllability and because there are both downstream and upstream versions, new terminology is in order.

The extension of the FocalCtrl is represented by the SLT I and the SLTs $E_{US}$ and $E_{DS}$, more specifically, $S_k = E_{US,k} + I_k + E_{DS,k}$ where $k$ indicates the path and $S_k$ is the cumulative lead time of path $k$ (cf. Figure 6). Note that $S$ does not extend as far upstream as is possible, i.e. additional flows may extend even further upstream, but B1b represents the reach of the flow being modelled. Also, the ability to control resources may be partial, which blurs the line between controllable and uncontrollable; this results downstream controllability decoupling zone (DCDZ) and upstream controllability decoupling zone (UCDZ), either of which may be process-based and/or

![Figure 9. External boundaries and relation to the LoE Focal Control.](image-url)
resource-based, in line with Wikner (2014a). However, the decoupling zones are not included in Figure 9 to avoid additional cluttering of the figure.

4.1.4. Driver of a flow (B3)

The boundary and controllability basically set the constraints for the actual mechanisms that apply to the flow. ExDC B1 is therefore central to flow analysis because it defines the limits of the system and ExDC B2 indicates the level of controllability. The actual trigger of the flow is however the ExDC B3 Flow driver, which represents the critical issue of why the flow is performed. Typical driver examples like forecast and customer order are related to the customer order decoupling point (CODP) (Giesberts & van der Tang, 1992; Hoekstra & Romme, 1992). As shown in Figure 10, ExDC B2 variants B2a and B2b are important in how they define the sequential interfaces between different LoEs, such as the PreCtrl, FocalCtrl and PostCtrl triad. Figure 10 illustrates a triad of three LoEs with different structures. The LoEs are defined from a controllability perspective and could equally well represent for example three different companies, three different sites, or three different departments in a company. Each LoE is defined by B2a and B2b as their respective extension, but illustrating the same configuration with the three extended LoEs (PreCtrl, index 1; PostCtrl, index 3; and FocalCtrl, index 2, in between) highlights the interfaces between the LoEs. Note that when B1 and B2 coincide only B1 is indicated in the more comprehensive part of Figure 10 to reduce the cluttering of the figure. The upstream extension of the controllable part of PostCtrl (EUS) corresponds to the downstream extension of PreCtrl (D1), i.e. the customer-order-driven element in PreCtrl is outside the control of PostCtrl, which is indicated by

\[ E_{US1-D1} \] is where a purchase order “meets” a customer order
\[ i.e. \ SinkDP_1 = SinkDP_2 = UCDP_3 \] and CODP_3 = SourceDP_3
\[ and \ E_{US1-D1} \] is where a move order “meets” a customer order

Figure 10. Interface between three logical entities in a triad.
diagonal striping of PreCtrl in Figure 10. The third LoE FocalCtrl is within the delivery lead time of PreCtrl and also controls the latter part of order fulfilment. This means that B2b related to UCDP of PostCtrl coincides with B1a (SinkDP) of PreCtrl, and because PreCtrl entrusts FocalCtrl to perform the final part of the transformation, the relation can be described as SinkDP₁ = SinkDP₂ = UCDP₃. Further upstream, B1b of PostCtrl represents the extension of PostCtrl, which coincides with the B3 (CODP) of PreCtrl, i.e. CODP₁ = SourceDP₃. Thus, the waiting time of PostCtrl corresponds to a delivery lead time D₁ of PreCtrl, which also covers the lead time of FocalCtrl to perform its task. For example (if it is assumed that the LoE corresponds to a LeE), PostCtrl releases a purchase order with lead time EUS₃, which at PreCtrl is received as a customer order with promised delivery lead time D₁, which means that $D₁ = E_{US,3}$. In the case of Figure 10, the FocalCtrl is performing a transformation corresponding to I₂, which is under the responsibility of PreCtrl in relation to PostCtrl. This scenario corresponds to PostCtrl ordering something from PreCtrl, which is responsible for the delivery, but FocalCtrl performs the actual delivery outside the control of PreCtrl. Note that the requested $D₁$ is longer than $S₂$, but there is no indication in this figure of the actual availability of this information to FocalCtrl. At the core of this example is the assumption that PreCtrl is responsible for the performance and then subcontracts FocalCtrl, which creates a principal–agent relation between the two LoEs in line with principal agent theory (Eisenhardt, 1989). In some cases, the driver is a compromise between forecast and certain customer orders, which is referred to as a customer order decoupling zone (CODZ), positioned upstream of the CODP but this is not included in Figure 10. The positioning of the CODP in PreCtrl is based on truly exogenous information ($D₁$) from the perspective of PreCtrl, and it may extend further upstream than $S₁$, resulting in positioning of CODP outside the modelled system, i.e. upstream of PreCtrl. Because the concept of CODP is general and generic and covers all parts of the system, any part of the system is either speculation driven or commitment driven. This is illustrated by the diagonal striping for the speculation-driven part and no striping for the commitment-driven parts, as shown for PreCtrl in Figures 10 and 11.

4.1.5. Differentiating a flow (B4a and B4b)

Decision category B3 only represents requests for something; it is not related to whether the request is standardized or individualized and this is instead related to B4 Flow differentiation. Differentiation for customers is a special case of variants created in the flow. The supply-based differentiation is independent of specific customer requirements and represents a point at which variants can be created in the flow (see, e.g. Duray, 2002). In Figure 11, three potential differentiation points, related to the decision category variant B4a Flow differentiation supply, are indicated by B4aᵢ, B4aᵢᵲ and B4aᵢᵲᵲ. These three points represent individualized variants that can be created in the flow but that require a specific delivery lead time, indicated by $A_{S,i}$, $A_{S,ii}$ and $A_{S,iii}$. While they are all candidates for individualization, individualization should not be performed before the customer order is received, which is represented by the SLT $D$. Comparing the three candidate lead times $A_{S,i}$, $A_{S,ii}$ and $A_{S,iii}$ with $D$ makes it possible to identify the possible individualization for a customer order. In Figure 11, only B4aᵢᵲᵲ is possible, because $A_{S,iii} < D$ and in this case is also used for offering individualization, meaning...
that decision category variant \( B_{4b} \) Flow differentiation demand is set to \( B_{4b} = B_{4a,iii} \) and \( A = A_D = A_{S,iii} \). This discontinuity – going from some level of standardization to an individualized offering – is related to the customer adaptation decoupling point (CADP). In relation to the CADP, at the lower part of Figure 11, the red line represents individualization and green line represents standardization (Wikner & Bäckstrand, 2018). Individualization could also be offered upstream of the CADP if orders are repetitive. This type of individualized solution, which is related to customization, is then represented by a customer adaptation decoupling zone (CADZ). In addition, the supply-based adaptation decoupling point (SADP) can be identified in relation to the candidates \( B_{4a_i}, B_{4a_{ii}} \) and \( B_{4a_{iii}} \), which each indicate a potential individualization, but these points are not shown separately in Figure 11 except for the CADP which coincides with the SADP of the last discontinuity, \( B_{4a_{iii}} \). Note, however, that if a CODZ is involved and a longer \( D \) is offered for individualized variants, then the CADP can be positioned upstream of the CODP but should not be positioned upstream of the CODZ. It is possible to position the CADP within a resource-based CODZ because this corresponds to a mix of speculation-driven and commitment-driven flows, and the commitment-driven flows may then be individualized. The CADP should not, however, be positioned upstream of CODZ because this would indicate that individualization is performed on speculation.

The risk related to creating variants is of course also related to the repetitiveness of demand. If a product is delivered only once to a customer, any kind of speculation would be futile. However, if the customer orders for that unique product are recurring, speculation might be used as indicated above. This line of reasoning can be generalized, in line with Table 2, where the frequency perspectives of customers and deliveries are combined. If an offering can be provided to more than one single customer and hence has multiple deliveries, it is classified as a customer generic (standard) offering, and if an offering is delivered only once, it is classified as delivery unique. As shown in Table 2, there is a compromise between these two cases, i.e. when a single customer has

![Figure 11](image-url)
recurring orders for the same product. This is referred to herein as a customer-unique offering and is represented by the process-based customer order adaptation zone (PB-CADZ), not included in Figure 11. Because the recurring orders open up some opportunity for speculation, the PB-CADZ can be positioned upstream from the CODP, but the end point of PB-CADZ, i.e. CADP, still should not be positioned upstream from CODP because the end point of the CADZ represents the upstream extension of only having delivery-unique offerings. In the case of single delivery and multiple customers, the assumption is that the customers turn up at different times. For single delivery and multiple customers, the problem basically becomes the classic newsboy problem (see, e.g. Silver, Pyke, & Peterson, 1998), wherein the challenge is to balance expected excess and expected shortage. This is based on a customer generic delivery but differs slightly from the customer generic with multiple deliveries and is highlighted with parentheses in Table 2.

4.1.6. Information shared in a flow (B5a, B5b and B5c)

The previous ExDCs B1–B4 are related to different types of decision-making, whereas the DC covered here only concern the observability of information for decision-making. Decision category variant B5a Flow observability demand is based on the availability upstream of information about external demand at B1a. The availability of information makes it possible to observe demand. This has also been referred to as the information decoupling point (Mason-Jones & Towill, 1999) but is here labelled demand information decoupling point (DIDP) to emphasize the relation to information about demand. Information about real demand, i.e. customer orders, must be available downstream from the CODP (without which it is impossible to act on customer orders) and hence the DIDP must be positioned between the B1b Flow boundary source (SourceDP) and the B3 Flow driver (CODP). The DIDP may in theory also be positioned outside the system and upstream of the SourceDP; in this case, the constraint related to B1b would be relaxed. Positioning the DIDP upstream from B3, as in Figure 12 where it is indicated by the blue arrow at the bottom of the figure, benefits the flow because the information available for speculation will be of better quality and cover previous real sales. In some cases, only partial demand information is available, and this is represented by a demand information decoupling zone (DIDZ) upstream of DIDP.

Correspondingly, the supply information related to observability of capacity is also important; this is covered by decision category variants B5b Flow observability supply sink and B5c Flow observability supply source. B5b concerns the availability of information about the available and required capacity of the downstream part of the LoE, and B5c concerns the corresponding information of the upstream part of the LoE. The availability of supply information is indicated by the corresponding downstream supply information decoupling point (DSIDP) and upstream supply information decoupling point (USIDP). Inside the LoE, the real capacity availability and capacity requirements

| Table 2. Different levels of uniqueness. |
|----------------------------------------|
| Single customer | Multiple customers |
|-----------------|--------------------|
| Single delivery | Delivery unique    |
| Multiple deliveries | Customer unique |
| (Customer generic) | Customer generic |
are known a priori, but this is not necessarily the case in the upstream or downstream part of the extended LoE, where they may be estimated by the LoE. The USIDP must therefore be positioned between the SourceDP and the UCDP, and the non-observable flow is indicated by grey shading in the lower part of figure. The DSIDP is positioned correspondingly. Only partial supply information may be available in this case, as well, and this is represented by the downstream supply information decoupling zone (DSIDZ) and the upstream supply information decoupling zone (USIDZ), which are not included in Figure 12.

4.1.7. Summary of exogenous decision categories
The ExDCs are derived from the SLTs, and four types of SLTs are sufficient to define the ExDCs, as shown in Figure 13:

- The fundamental ExDC is B1; it represents the end points of the flow with the extension S, which positions the source in relation to the sink, i.e. the extension of the flow and hence the system boundary.
- Ratio-based ExDCs include B2, B3 and B4; these are based on lead-time ratios that indicate the positioning of the corresponding DPs. Figure 13 illustrates this by the relation of some ExDCs to two SLTs. This means that the DPs of each of these ExDCs are positioned in relation to two SLTs.
- The additional ExDC is B5; it is only related to observability and thus to information available for decision-making, whereas B1–B4 represent actual decision-making. In Figure 13, B5 is related to limitations of the observability of the system and constraining B2 for supply and B3 for demand.

The arrows in Figure 13 are from the SLTs to the ExDC and indicate the axiomatic dependency of each ExDC on the SLTs. B1 is only based on S because this is the relative positioning of B1a and B1b. B2 is based on S and I, which in turn is related to the Es. B3 is positioned based on D in relation to S (even if D alone would suffice if the positioning inside or outside the boundary is of no concern). B4 requires knowledge of D when A is

![Figure 12. Information sharing related to supply and demand.](image)
selected, and B5 is limited for the demand information by D, whereas the supply information is related to I, i.e. the internal part of the LoE.

The set of exogenous decision categories ExDCs is hereby complete; Table 3 provides a summary of the ExDCs and some key terminology. The first and second columns contain the identifications (IDs) and the names referred to above. The IDs are based on the exogenous property and begin with a B for boundary-based. Each decision category is also related to a decision criterion, reflecting the type of decisions involved. The three columns on the right are instead focused on the discontinuity represented by a decoupling point DP and the decision domains upstream (Pre-DP) and downstream (Post-DP) from each DP.

4.2. **Endogenous decision categories**

Decision-making in a flow context involves decisions based on external factors such as customer demand or the controllability of the flow. These aspects are covered by the ExDCs. Other decisions are based not on external factors but on factors internal to the system (of endogenous character). This could, for example, concern how planning and control are performed and characteristics of objects in the flow. These decisions are related to the endogenous decision categories, EnDCs, and are based on properties internal to the LoE. Because flow thinking is based on flow discontinuities, but not on the SLTs per se, the EnDCs complement the ExDCs in the sense that EnDCs are not based on SLTs but instead are categorized in relation to the CPs shown in Figure 8.

![Figure 13. The five ExDCs and the four TPs.](image)

| ID | Decision category (DC) (discontinuity type) | Decision criterion | Decision domain Pre-DP property | Decoupl. point (DP) | Decision domain Post-DP property |
|----|---------------------------------------------|-------------------|--------------------------------|-------------------|---------------------------------|
| 1 (B1a) | Flow boundary sink | Inclusion | Internal | SinkDP | External |
| 1 (B1b) | Flow boundary source | " | External | SourceDP | Internal |
| 2 (B2a) | Flow controllability sink | Influence | Controllable | DCDP | Uncontrollable |
| 2 (B2b) | Flow controllability source | " | Uncontrollable | UCDP | Controllable |
| 3 (B3) | Flow driver | Driver | Speculation | CODP | Commitment |
| 4 (B4a) | Flow differentiation supply | Uniqueness | Potentially stand. | SADP | Potentially individ. |
| 4 (B4b) | Flow differentiation demand | " | Standardized | CADP | Individualized |
| 5 (B5a) | Flow observability demand | Transparency | Estimated demand | DIDP | Real demand |
| 5 (B5b) | Flow observab. supply sink | " | Real supply | DSIDP | Estimated supply |
| 5 (B5c) | Flow observ. supply source | " | Estimated supply | USIDP | Real supply |
point of departure is a process view of the LoE with transformation at its core, as illustrated in Figure 14, where the boundary dimension has already been covered by the ExDCs. The EnDCs are related to the remaining three endogenous dimensions. The first dimension is the provisioning of the offering, referred to as the transformation dimension (T) because it involves the actual transformation performed. The second dimension is the resource dimension (R), which is crucial in terms of performing the transformation. The third and final category is the control dimension (C), which is related to aspects of how to perform the transformation. Because the EnDCs are based on selections in relation to the CPs, the role of the zones is less prominent for EnDCs than for ExDCs.

4.2.1. The logic behind the endogenous decision categories

The logic used to derive the EnDCs depends on the perspectives applied in using the constructs rather than being derived axiomatically from the SLTs. Different approaches are therefore possible, but because the focus here is on flow design, the CPs of Figure 8 are used. Note that the CPs are basically different aspects of the flow from a process perspective, where process refers to the transformation logic. The logic used here is therefore related to process analysis and is proposed as a complement to the five ExDCs outlined above. The EnDCs are based on the three endogenous dimensions of Figure 14: the transformation dimension, the resource dimension and the control dimension. The four CPs used to identify the five EnDCs of Figure 15 are based on the key flow perspectives. The EnDCs are derived using five questions following the logic of process analysis: What is being transformed? What is performing the transformation? and How is the transformation managed? These questions are numbered consecutively from six since they are considered as a logical continuation of the five questions posed in relation to the ExDCs:

6. What are the key properties of the objects being transformed?
   The objects are subject to transformation in the system.

7. What are the key properties of the network structure for transformation?
   The network represents the configuration of the transformation in the system.

8. How are the customers interacting with the resources of the system?
   The customers interact in different ways with the resources of the system.
9. What are the key properties of the resources performing the transformation?
   The resources have some constraints regarding how they can perform the transformation.

10. How should the system of objects, customers and resources be controlled?
    Controlling complex systems requires a holistic and adaptable approach.

4.2.2. Objects being transformed (T1a and T1b)
The EnDC T1 Object type is fundamental in the transformation of physical goods. It represents the properties of the physical goods transformed in the system and emphasizes the difference between continuous objects (products), e.g. liquids and powders measured in for example volume or weight, in contrast with discrete objects that can be counted in pieces. The point in the flow where the object is discretized, also referred to as a discretization point (Abdulmalek, Rajgopal, & Needy, 2006), is related to T1a Object type discretize. T1a captures the change from continuous objects (e.g. liquids) to discrete objects (e.g. bottles of liquid) and is related to the discretization decoupling point (DDP). The object continuization represents the reverse situation where discrete objects are transformed into continuous objects and is related to T1b Object type continuize. T1b, correspondingly referred to as the continuization decoupling point (CDP), based on Wikner and Noroozi (2016), where e.g. containers of liquids are emptied. Note that sometimes the discrete objects can be modelled, i.e. perceived, as continuous if the volume is sufficient to approach the objects from a rate-based perspective.

4.2.3. Network structure for transformation (T2a and T2b)
The EnDC T1 is based on fundamental physical properties of the object. The EnDC T2 Network breadth instead focuses on the flow network and how the flow objects are split or joined, cf. VAX and IVAT classifications (Goldratt, Fox, & Grasman, 1986; Oden, Langenwalter, & Lucier, 1993). These network properties are also illustrated by the flow configurations in Figure 4. Splitting is basically related to diverging flows and T2a Network breadth split whereas joining is related to converging flows and T2b Network breadth join, which make the network wider or narrower, respectively. Diverging flows are a typical property of process industries (form diverging) and distribution (place diverging), but converging flows are more typical for discrete manufacturing industries and the construction industry. These splits and joins are key control points in network structures and are key to flow management (see, e.g. Umble & Srikanth, 1997). The point where flows converge is referred to as the network join decoupling point (NJDP), and the point where flows diverge is referred to as the network split decoupling point (NSDP). By combining NJDP and NSDP, it is possible to represent more complex and composite transformation networks.

4.2.4. Customers interacting with resources (R1a and R1b)
The EnDC R1 Customer contact is the contact point between the resources and the customers. Customer contact is usually associated with the concepts of ‘back office’ and ‘front office’ and is based on the interaction between the customer and the provisioning system (Chase, 1978). In this context, the exogenous property of the DC may be emphasized as the customer is involved. The actual contact with the customer, however,
is usually not decided per se by the offering but is in most cases a matter of system design; therefore, it is an issue related to the resource dimension. This type of customer contact is very decisive for the customer experience and has even been described as related to the ‘moment of truth’ (Carlson, 1987). This moment is the criterion for interaction where the part of the system concerned can be perceived as open or closed by the customer. This EnDC is mainly used in the context of service provisioning, and the downstream customer contact decoupling point (DCCDP) separates back-office from front-office activities along the flow across R1a Customer contact enable. In some cases, a front-office activity is followed by a back-office activity, and in this case, the discontinuity would be represented by the upstream customer contact decoupling point (UCCDP) and R1b Customer contact disable.

4.2.5. Resources performing the transformation (R2a and R2b)
Capacity is the key property of a resource, and the main characteristic of the capacity is related to the EnDC R2 Resource type. Type here refers to the capacity of a resource or set of resources, classified as either finite or infinite. By considering stock points as resources as well, limited storage space is also included. The level of finiteness is basically related to the classification of resources as bottlenecks (finite and constraining) or non-bottlenecks (infinite or finite but non-constraining). The point that separates two different types of resource finiteness in the flow is referred to as an upstream resource finiteness decoupling point (URFDP) if the finiteness is relaxed with the flow at R2a Resource type relax. The opposite is referred to as R2b Resource type constrain where a downstream resource finiteness decoupling point (DRFDP) is positioned where the infinite resources are succeeded by finite resources in the flow.

4.2.6. Controlling the transformation system (C1a, C1b, C1c, C1d, C1e and C1f)
The EnDC C1 Control mode is crucial from a flow management perspective as it decouples the flow into parts with homogenous properties from a planning and control perspective. The control mode decoupling point (CMDP) corresponds to the interface between different types of control approaches. An overall classification usually identifies three different modes, where the onetime mode (OM) is the most infrequent flow and continuous mode (CM) is the most frequent flow. An intermittent mode (IM) is possible when, for example, different types of batch flows are controlled (see, e.g. Wikner & Noroozi, 2016). From a more general perspective, the relevant events can be used as a baseline for execution of activities: individual events where activities are pegged in networks; group of events where activities are time-phased and collected in time buckets; and finally inseparable flow of events where activities are rate based. The CMDP is in this sense a more generic DP than the others in the ontology as it applies to discontinuities between three different modes and therefore represents interfaces between different levels of repetitiveness. In total, a CMDP can be involved in six different types of discontinuities, where the three types of modes are significant and they are sequence dependent. The six tuples C1a to C1f are then (using the notation upstream-downstream for combining control modes): OM-IM, OM-CM, IM-OM, IM-CM, CM-OM and CM-IM. Using the previous logic of alphabetical ordering of variants this would correspond to six different discontinuities: C1a Control mode OM-IM, C1b Control mode OM-CM, etc.
4.2.7. Summary of endogenous decision categories

The EnDCs compose a dynamic set of decision categories, and depending on the CPs involved, the set may be larger or smaller depending on the analysis being performed. This is in contrast to the ExDCs, which are considered a fixed set of decision categories as they are derived from a systems approach based on SLTs. For the ‘standard’ CPs outlined above, most, if not all, EnDCs are important, but the key relations for each are outlined below and illustrated in Figure 15:

- Customers and services is in particular based on the EnDC R1, as this captures the essence of classifying services as front office or back office. Because controllability concerns the capability of resources and the delivery to customers, it is also important to consider the EnDC R2.
- Products and processes is based on products and therefore the EnDC T1 is important. In addition, the structure of the processes performed is key, and this is related to the EnDC T2.
- Resources and capacity is a straight descendent of the EnDC R2, but T1 provides requirements on the type of resources that can be used for different types of transformations. In addition, the EnDC C1 is important for resource management.
- Planning and control is general and concerns all five EnDCs because they all affect the preconditions for planning and control of the flow.

A second set of decision categories, the EnDCs, is now complete, and Table 4 provides a summary of the EnDCs and some key terminology. The structure of Table 4 is the same as that of Table 3. The first and second columns contain the IDs and the names referred to above. The IDs are based on the dimensions of Figure 14, with the initial letter of the ID based on the related dimension. The decision categories are also related here to a decision criterion reflecting the type of decisions involved. Also, the three columns on the right focus on the discontinuity represented by a DP and the decision domains upstream and downstream from each DP.

4.3. Summary of the ontology for flow thinking

The purpose stated initially was to ‘develop an ontology for flow thinking based on decoupling points, which is used to unravel a control logic that can be applied to lean thinking and value-stream analysis as well as other contexts to support not only cost efficiency but also competitiveness based on effective differentiation strategies’. The

![Figure 15. The five EnDCs and the four CPs.](image)
suggested approach is to investigate discontinuities of the flow to highlight where the preconditions for the flow change. This approach separates the flow into different flow segments and each flow segment is a candidate for the missing level of SCO management in Table 1, which could be labelled ‘control item’. Hence the division of a product into ‘control items’ is related to the discontinuities and also coincides, to some extent, with the concept of master scheduled items (see, e.g. Jacobs, Berry, Whybark, & Vollmann, 2011). These discontinuities have been identified by using two different approaches. First, the ExDCs were identified using a time-based approach wherein the TPs were used to derive the DCs. Second, the CPs guided the identification of the EnDCs. The boundary-based ExDCs are usually all-important when flow thinking is applied, but some of them may in some instances not be explicitly included. The EnDCs are included based on the objective of the analysis, and thus none, some, or all of them might be included. Table 5 provides a complete overview of the different types of DCs, a concept in line with the DCs of Hayes and Wheelwright (1984) but structured here in a different, flow-based, way. The DCs of Hayes and Wheelwright are more related to the physical perspective whereas these DCs are based on the logical perspective. Each DC is related to a discontinuity type and a DP, with pre-DP and post-DP properties as indicated in Table 5. In total, 10 DCs were identified in response to the 10 questions that were stated when outlining the logic in relation to the ExDCs and the EnDCs (five questions each). This was then used as a point of departure for identification of the two subsets of DCs. Including all the variants, the total set of DCs includes 10 plus 14, i.e. 24 DC variants. For example, the DC B1 has two variants: B1a and B1b. The variants are basically different versions of a DC based on the same logical definition.

Finally, the relation between the DCs and the TPs and the CPs is summarized in Figure 16, which is a combination of Figures 13 and 15, with the same foundation as Table 5. This figure includes all 10 main DCs that together constitute the ontology of flow thinking. The figure also captures the relationships between the ExDCs and the TPs as well as the relationships between the EnDCs and the CPs, as explained separately above in relation to Figures 13 and 15.

### 5. Application of the flow-thinking ontology

The developed ontology can be applied to a wide range of cases and for different purposes. It is based on some fundamental concepts that are of interest in basically all

| ID | Decision category (DC) | Decision criterion | Decision domain Pre-DP property | Decoupling point (DP) | Decision domain Post-DP property |
|----|------------------------|--------------------|---------------------------------|----------------------|---------------------------------|
| 6  | (T1a) Object type discretize | Unit | Continuous | DDP | Discrete |
|   | (T1b) Object type continuize | * | Discrete | CDP | Continuous |
| 7  | (T2a) Network breadth split | Branching | Narrow | NSDP | Wide |
|   | (T2b) Network breadth join | * | Wide | NJDP | Narrow |
| 8  | (R1a) Customer contact enable | Moment | Closed | DCCDP | Opened |
|   | (R1b) Customer contact disable | * | Opened | UCCDP | Closed |
| 9  | (R2a) Resource type relax | Finiteness | Constrained | URFDP | Unconstrained |
|   | (R2b) Resource type constrain | * | Unconstrained | DRFDP | Constrained |
| 10 | (C1a-C1f) Control mode <from-to> | Repetitiven. | Upstream mode | CMDP | Downstream mode |
types of flow management. The ontology can be applied in a stand-alone fashion or integrated with other methods. To illustrate this versatility, three applications are outlined below based on examples from the literature. First, a basic lead-time analysis is outlined using a time-phased product structure. This example highlights the application of the ontology to identify the discontinuities in relation to a product structure. Next, a flow design case is used to illustrate both the potential for establishing standardized flow modules, separated by discontinuities, and for providing a foundation for designing the planning and control methods to be applied. This example also illustrates an industry specific application as it is based on a process industry example. Finally, a value stream map is used as a point of departure for illustrating how the

| ID   | Decision category (DC) (Discontinuity type) | Decision criterion | Decision domain Pre-DP property | Decoupling point (DP) | Decision domain Post-DP property |
|------|--------------------------------------------|--------------------|---------------------------------|----------------------|-----------------------------------|
| 1 (B1a) | Flow boundary sink | Inclusion | Internal | SinkDP | External |
| (B1b) | Flow boundary source | " | External | SourceDP | Internal |
| 2 (B2a) | Flow controllability sink | Influence | Controllable | DCDP | Uncontrollable |
| (B2b) | Flow controllability source | " | Uncontrollable | UCDP | Controllable |
| 3 (B3) | Flow driver | Driver | Speculation | CODP | Commitment |
| 4 (B4a) | Flow differentiation supply | Uniqueness | Potentially stand. | SADP | Potentially individ. |
| (B4b) | Flow differentiation demand | " | Standardized | CADP | Individualized |
| 5 (B5a) | Flow observability demand | Transparency | Estimated demand | DIDP | Real demand |
| (B5b) | Flow observ. supply sink | " | Real supply | DSIDP | Estimated supply |
| (B5c) | Flow observ. supply source | " | Estimated supply | USIDP | Real supply |
| 6 (T1a) | Object type discretize | Unit | Continuous | DDP | Discrete |
| (T1b) | Object type continuize | " | Discrete | CDP | Continuous |
| 7 (T2a) | Network breadth split | Branching | Narrow | NSDP | Wide |
| (T2b) | Network breadth join | " | Wide | NJDP | Narrow |
| 8 (R1a) | Customer contact enable | Moment | Closed | DCCDP | Opened |
| (R1b) | Customer contact disable | " | Opened | UCCDP | Closed |
| 9 (R2a) | Resource type relax | Finiteness | Constrained | URFDP | Unconstrained |
| (R2b) | Resource type constrain | " | Unconstrained | DRFDP | Constrained |
| 10 (C1a-C1f) | Control mode <from-to> | Repetitiven. | Upstream mode | CMDP | Downstream mode |

Figure 16. The DCs of the flow thinking ontology.
ontology can be used to extend a classical value-stream analysis. A value stream map from the literature is extended with concepts from the ontology to highlight some aspects of discontinuities previously not emphasized by the mapping approach.

5.1. Application for analysis of strategic lead times and decoupling points

The first application covers a time-phased product structure based on Wikner (2014a), as schematically shown in Figure 6. This example concerns a product with items and identification of DPs and hence concerns levels 1–3 in Table 1. Figure 17 provides an overview from a lead-time perspective of the ExDCs and the corresponding SLTs and DPs. The boundary of the system is indicated by SourceDP and SinkDP, and the internal/external meaning is indicated by the box encapsulating the internal as well as external parts of the structure. Correspondingly, the controllability is indicated by UCDP and DCDP and they have index to indicate the branch with the controllable segment. The product is finalized to customer order, but in this case, the final item Z is uncontrollable, meaning that it is under control of the customer, which may have ‘purchased capacity’ to produce Z and then decides on the timing for producing Z. The actual use of capacity is however visible, which is indicated by the position of the DSIDPZ. The discontinuities are based on exogenous factors, where D is six time-units, corresponding to items X, Y and Z, where Z is individualized for each customer order (indicated by red). D and the individualization are reflected in the positioning of CODP and CADP, respectively. U could also be individualized, as indicated by SADPU, but because CODP is positioned downstream of SADPU and no CODZ is involved, it is not possible to utilize that opportunity; instead, the product is individualized from CADP. Both CODP and CADP can only exist one each in a system and therefore no index is required for them. The items Q and V are purchased and outside the control of the LoE FocalCtrl, resulting in the position of the USIDPs. There is visibility for the supply of V but not for Q, hence the positioning of the USIDPs. This overview of the flow characteristics of product Z provides important information, e.g. for the planning and control of the product, such as the impact of customer orders on the different items.

5.2. Application for analysis of modularized supply-chain design

The second application is used to illustrate how the ontology can be employed for application of flow thinking to a modularized approach to flow design. This example concerns a LoE and the processes related to it. In this sense it mainly concerns level 2 in Table 1, but as this example is based on an enterprise also level 1 is relevant, and in addition level 3 due to the DP based analysis. The example in Figure 18 is based on the approach outlined in Wikner and Noroozi (2016). In this case, it is a process industry (PI) enterprise, where one plant corresponds to the LoE and the example covers only that particular LoE. The PI labels and delivers the packaged good based on customer orders (commitment) but all other activities are performed based on forecasts (speculation). Some minor individualization is performed in the flow where the customer order is received. All necessary demand and supply information is available in the plant. The material is continuous upstream from packaging, i.e. the leftmost cube in Figure 18. The planning and control applied is rate-based (CM) upstream of packaging and
subsequently is batch-wise (IM). In the schematic application of the ontology in Figure 18, the external boundaries B1a and B1b are given as the plant and thus everything included in the example is controllable, meaning that B2a = B1a and B2b = B1b. The driver is explicitly mentioned and B3 is included in the model. As mentioned, the individualization corresponds to the customer-order-driven flow, meaning that B4b is positioned at B3, i.e. CADP = CODP (= SADP). All necessary information is available, meaning that information about customer orders is available for at least the commitment-driven part, which corresponds to the positioning of DIDP at, or upstream from, CODP (B5a and B3); additionally, all capacity related information is available, and thus DSIDP = DCDP (B5b = B2a) and USIDP = UCDP (B5c = B2b). Two EnDCs are used in this example, and the DDP of T1a is positioned where packaging creates discrete objects (graphically, all types of DPs related to EnDCs are illustrated by a circle). Finally, the control-mode C1f is applied where the continuous mode (CM) is replaced by the intermittent mode (IM), where CM is applied upstream and IM is applied downstream from the DDP. Hence, there are three dimensions explicitly involved: B3, T1a and C1f, as illustrated by the three-dimensional cuboid at the right of Figure 18 (space has been inserted between the horizontal layers to make all modules in the cuboid visible). The light grey modules at the top are not viable because the onetime mode (OM) should not be combined with speculation-driven or continuous objects. This flow configuration is related to the three orange modules of the cuboid and then illustrated as a flow at the bottom left, where the LoE and the DPs are indicated. In summary, the flow consists of three different flow segments based on combining CODP, DDP and CMDP and can be classified as a sequence of modules of types (based on Wikner & Noroozi, 2016): CO–CM–SD; DO–IM–SD; DO–IM–CD, where the interfaces between the modules represent flow discontinuities.
Lean thinking emphasizes continuous flow as the ultimate vision, but in theory as well as in practice, this is rarely possible to realize. Because the preconditions for the flow change over time and because the value-adding flow takes time, at least for physical flows, the preconditions for flow change along the flow. This is where flow thinking, which takes these discontinuities into explicit consideration, complements lean thinking and value-stream analysis. It is therefore important to note that this type of discontinuity analysis does not replace, but rather complements, value-stream analysis. Figure 19 provides a condensed overview of some aspects that may be included in value-stream analysis using an example of a mixed model value stream from Duggan (2013).

This example focuses on the ExDCs of the TPs, as these should have general relevance and always be applicable. The value stream in this case is delimited by SourceDP and SinkDP, and as all parts of the value stream are controllable, UCDP coincides with SourceDP and DCDP coincides with SinkDP. In addition, information is available about all parts of supply, and thus USIDP and DSIDP are positioned at the controllability DPs. All deliveries are based on customer orders, and hence CODP is positioned at the supermarket of the make-to-stock items. Interesting enough the concept of separating customer order driven flow from forecast driven was introduced by one of the earlier contributors to lean thinking (Shingo, 1989). This concept has, however, only received limited attention in relation to value stream mapping which may be due to different reasons (Serrano Lasa, Castro, & Laburu, 2009) but is also explicitly included in some cases (see, e.g. Hines & Rich, 1997; Naylor et al., 1999). This particular case concerns a product family that can be individualized, but most of the variants are standardized and therefore the CADP is positioned before delivery (all deliveries are individualized in terms of where the products are delivered to), but downstream from the CODP. The CADP is positioned at delivery to indicate that, in this particular case, the actual delivery is the only aspect that is individualized in both form and place for all orders. If the analysis only focused on form – the physical product itself – then the CADP would be
positioned at the end of the value stream as the product family includes standard products. A buffer inventory is kept of some items (the supermarket in parallel with the rightmost FIFO lane) and even if most production is based on customer orders, some may be delivered from stock, i.e. the supermarket. Hence, the resources are subject to a mix represented by RB-CODZ, and the corresponding DIDP is positioned upstream of RB-CODZ to enable customer orders to drive the flow. Also, the products may be standardized or individualized in the flow, meaning that the resources face a mix of different levels of individualization, which corresponds to resource-based CADZ, i.e. RB-CADZ. The value stream map from lean thinking provides key information, e.g. in terms of value-add analysis and the decoupling analysis from flow thinking provides key information on control points.

6. Conclusions and further research

Decision-making is the core element of management and has received considerable attention over the years. From an operational perspective, the efforts to improve efficiency have been in focus and continuous improvement to reduce the consumption of cost and time are key challenges. Improving efficiency without effectiveness is, however, futile, as pointed out by Drucker (1966). Lean thinking has provided a multitude of tools focusing on improving efficiency. Effectiveness and agility have not been ignored in lean, but neither have they been core elements as such (see, e.g. Naim & Gosling, 2011). Flow thinking, as outlined above, has the opposite strengths and weaknesses. The focus of flow thinking is on effective decision-making, but limited support is provided on how to make the flow efficient. Due to these asymmetrical characteristics of the two approaches, they constitute a perfect complementary match. Lean thinking provides a multitude of tools for making flows efficient and flow thinking contributes with an approach that supports effective decision-making. From this
perspective, the suggested approach complements already established tools used in lean implementations (see, e.g. Mostafa, Dumrak, & Soltan, 2013). Flow thinking is, however, not limited to the context where lean is applied. The approach provides insights in all value adding contexts where process-based management is employed. Flow thinking provides a control structure that supports an elaborate perspective of planning and control where the discontinuities represent candidates for key control points.

Due to the generic approach employed in the derivation of the ontology it is versatile and applicable in most types of industrial contexts. The ExDCs have been highlighted as fundamental, generic and applicable in all types of industries. This is however not necessarily the case for all the EnDCs since they are targeting conversion aspects which differ between different industries. For example the T1 Object Type is basically only of relevance for the process industry as it represents the foundation for the definition of process industry which is based on the presence of continuous objects (Abdulmalek et al., 2006). In a similar vein the R1 Customer Contact is mainly key for the service industry as it highlights the distinction between front-office and back-office activities (see, e.g. Chase, 1978) even if the topic of customer contact may also be significant for other industries, and in particular if they are customer-driven.

For further research it would be of interest to gain a better understanding of the DCs, in particular the intersection of several DCs. Once the fundamental logic is established, the next step would be to outline a methodology for using the ontology in both research projects and practical applications where the 10 questions utilized here can be used as a point of departure. It will also be important to validate the approach in different types of industries. Since the methodology provides a structural framework for flow analysis it has also potential for enabling effective implementation of industrial digitalization and the application of AI in industrial contexts. Finally, the ontology would benefit from a thorough validation of the flow-thinking approach across a wider set of cases. Parts of the methodology has been validated through cases (see, e.g. Bäckstrand, 2012; Wikner & Bäckstrand, 2018; Wikner, Yang, Yang, & Williams, 2017) but with this developed ontology a more holistic approach to investing the applicability through case studies could provide substantial additional insights.

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No potential conflict of interest was reported by the author.

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### Appendix  Key abbreviations used in the text

| Abbreviation | Description |
|--------------|-------------|
| A            | Adapt lead time |
| B            | Boundary dimension |
| C            | Control dimension |
| CADP         | Customer Adaptation Decoupling Point |
| CADZ         | Customer Adaptation Decoupling Zone |
| CD           | Commitment Driven |
| CDP          | Continuation Decoupling Point |
| CM           | Continuous Mode |
| CMDP         | Control Mode Decoupling Point |
| CO           | Continuous Object |
| CODP         | Customer Order Decoupling Point |
| CODZ         | Customer Order Decoupling Zone |
| CP           | Conversion Perspective |
| D            | Delivery lead time |
| DC           | Decision Category |
| DCDP         | Downstream Controllability Decoupling Point |
| DCCDP        | Downstream Customer Contact Decoupling Point |
| DCDZ         | Downstream Controllability Decoupling Zone |
| DDP          | Discretization Decoupling Point |
| DRFDP        | Downstream Resource Finiteness Decoupling Point |
| DIDP         | Demand Information Decoupling Point |
| DIDZ         | Demand Information Decoupling Zone |
| DO           | Discrete Object |
| DP           | Decoupling Point |
| DSIDP        | Downstream Supply Information Decoupling Point |
| DSIDZ        | Downstream Supply Information Decoupling Zone |
| DZ           | Decoupling Zone |
| E            | External lead time |
| EnDC         | Endogenous Decision Category |
| ExDC         | Exogenous Decision Category |
| FocalCtrl    | Focal Control |
| I            | Internal lead time |
| ID           | Identification |
| IM           | Intermittent Mode |
| L            | Lead time |
| LeE          | Legal Entity |
| LoE          | Logical Entity |
| NJDP         | Network Join Decoupling Point |
| NSDP         | Network Split Decoupling Point |
| OM           | Onetime Mode |
| PB           | Process Based |
| PhE          | Physical Entity |
| PostCtrl     | Post Control |
| Post-DP      | Post Decoupling Point |

(Continued)
(Continued).

| Abbreviation | Description                           |
|--------------|---------------------------------------|
| PreCtrl      | Pre Control                           |
| Pre-DP       | Pre Decoupling Point                  |
| R            | Resource dimension                    |
| RB           | Resource Based                        |
| S            | System lead time                      |
| SADP         | Supply-based Adaptation Decoupling Point |
| SADZ         | Supply-based Adaptation Decoupling Zone |
| SCO          | Supply Chain and Operations           |
| SD           | Speculation Driven                    |
| SinkDP       | Sink Decoupling Point                 |
| SLT          | Strategic Lead Time                   |
| SourceDP     | Source Decoupling Point               |
| T            | Transformation dimension              |
| TP           | Time Perspective                      |
| UCDP         | Upstream Controllability Decoupling Point |
| UCCDP        | Upstream Customer Contact Decoupling Point |
| UCDZ         | Upstream Controllability Decoupling Zone |
| URFDP        | Upstream Resource Finiteness Decoupling Point |
| USIDP        | Upstream Supply Information Decoupling Point |
| USIDZ        | Upstream Supply Information Decoupling Zone |
| VMI          | Vendor-Managed Inventory              |