The 2-dimensional CODP for customization in ETO contexts

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Abstract
Customization and engineer to order (ETO) are gaining interest in practice as well as in research. Providing such customer unique solutions is important for competitiveness in high cost environments and to support such operations the theory must support an integrated view of engineering and production. The 2-dimensional customer order decoupling point (CODP) is such a concept and it has gained considerable interest. The concept has extended the reach for decoupling thinking but still offers several avenues for further research. Three extensions are suggested: initial engineering, strategic lead-times and customization. Cases are used to illustrate the usefulness of the extended theory.

Keywords: ETO, customization, decoupling point

Introduction
The importance of being able to offer short delivery lead-times to prospective customers is nothing new (Stalk & Hout, 1990) but still emphasised (Godinho Filho & Saes, 2013). The same goes for the demand for customizations and the market uncertainty (Oeser, 2015; Wortmann, Muntslag, & Timmermans, 1997). Short delivery lead-times speak in favour of developing and producing the products ahead of receiving customer orders, i.e. based on forecasts, while customization and market uncertainty speak against. Using a customer order decoupling point (CODP) in the form of a stock point of semi-finished products to handle this trade-off and decouple the activities based on forecasts from those based on customer orders is frequently used for production (Hoekstra & Romme, 1992) as well as distribution (Rudberg & Wikner, 2004). However, when the customizations require engineering activities and the work of design engineers, the CODP may decouple engineering activities (i.e. an engineering decoupling point). The use of decoupling thinking in engineering is not as common as in production, which is discussed in Wikner and Rudberg (2005) where they extend the decoupling thinking to also include an engineering dimension besides a production dimension in a 2-dimensional CODP. Wikner and Rudberg (2005) state that the traditional view with only one dimension assumes a linear continuum where all engineering activities are performed before any production activities can start and argue that this does not reflect reality where engineering and production can be performed concurrently. Dekkers (2006) also discusses a 2-dimensional CODP together with the use of modular product architecture. Following Wikner and Rudberg (2005) and Dekkers (2006), Gosling, Hewlett, and Naim

(2017) introduced a framework for classifying different engineering decoupling points to describe to what extent engineering activities are based on customer orders.

Wikner and Rudberg's (2005) framework has gained a rather large deployment and has, for example, been used for describing customization strategies within housebuilding (Johnsson, 2013), shipbuilding (Semini et al., 2014), the clothing industry (Martínez, Errasti, & Rudberg, 2015), and the machine tool sector (Cannas, Pero, & Rossi, 2017).

In some of the applications of Wikner and Rudberg's (2005) 2-dimensional CODP, there seems to be ambiguities regarding: the customization strategies in terms of the differences between "pure" engineer-to-order (ETO) and adapt-to-order (ATO), the lead-time perspective, and more explicitly recognised customization separated from the driver. The purpose of the research presented in this paper is therefore to elaborate and extend the 2-dimensional CODP for customization in ETO contexts to clarify different customization strategies.

Methodology

A combination of 'analytical conceptual' and 'empirical case study' research (Wacker, 1998) was used to investigate how to elaborate and extend the 2-dimensional CODP for customization in ETO contexts. The analytical conceptual research brings new insights into traditional problems through logical relationship building and conceptual models (Meredith, 1993) and deduction (Voss, Tsikriktsis, & Frohlich, 2002). The point of departure of our analytical conceptual research was the existing 2-dimensional framework by Wikner and Rudberg (2005). Empirical data from two case companies are used to illustrate the resultant conceptualizations, in line with the description by Wacker (1998).

The two case companies are Fagerhult belysning AB (henceforth Fagerhult) and Siemens Industrial Turbomachinery AB (henceforth Siemens) that are manufacturing companies producing both standard and customized products and the chosen plants are located in Sweden. Empirical data regarding the case companies' products, engineering strategies and production strategies, were gathered through interviews, observations, documents and workshops.

Literature review

A fundamental property of product realisation is that engineering must precede production, reflecting that engineering defines the product and production delivers the product. Despite this sequential property, the complete process of engineering and production activities may be configured in several different ways when the flow driver is considered. Even if engineering must precede production in general, it is not valid for the complete product as one integrated entity. A product can be disintegrated into several activities and for each activity this sequence constraint is valid, i.e. it must be engineered before it is produced. However, when these activities are aggregated to a product the result is a process network of many engineering and production activities where some production activities of some items can be performed before engineering activities for other items. Some activities are forecast driven (FD) whereas others are customer order driven (CD). Table 1 combines the two drivers (FD and CD) with the two dimensions from Wikner and Rudberg (2005), i.e. the engineering dimension (ED) and the production dimension (PD). This results in four building blocks that can be configured into the six possible strategies discussed in Wikner and Rudberg (2005).

In Table 2 the six possible strategies are defined in line with Wikner and Rudberg (2005). If all engineering activities are based on customer order (CD_{ED}) all production activities must also be based on customer order (CD_{PD}) and this is reflected by strategy 1 in Table 2. However, if all engineering activities are performed based on forecasts (FD_{ED}), the production activities may be based on any mix of customer orders and forecasts (mix of FD_{PD} and CD_{PD}) which is reflected by strategies 3, 4 and 5 in Table 2. Finally, if some engineering activities are based on forecasts and some on customer order (mix of FD_{ED} and CD_{ED}), it is possible to perform some production activities on speculation (FD_{PD}+CD_{PD}, strategy 6), but not necessary (CD_{PD}, strategy 2).

Table 1 - The four building blocks of the integrated engineering-production framework

	Forecast Driven (FD)	Customer order Driven (CD)
Engineering Dimension (ED)	FD_{ED}	CD_{ED}
Production Dimension (PD)	FD_{PD}	CD_{PD}

Table 2 - Six strategies for engineering in combination with production

Strategy	FD_{ED}	CD_{ED}	FD_{PD}	CD_{PD}	ED-PD
1	-	X	-	X	Engineer-to-order, Make-to-order ETO_{ED}-MTO_{PD}
2	X	X	-	X	Adapt-to-order, Make-to-order ATO_{ED}-MTO_{PD}
3	X	-	-	X	Engineer-to-stock, Make-to-order ETS_{ED}-MTO_{PD}
4	X	-	X	X	Engineer-to-stock, Assemble-to-order ETS_{ED}-ATO_{PD}
5	X	-	X	-	Engineer-to-stock, Make-to-stock ETS_{ED}-MTS_{PD}
6	X	X	X	X	Adapt-to-order, Assemble-to-order ATO_{ED}-ATO_{PD}

The six strategies outlined above represent different combinations of engineering and production activities. Five of these strategies can be positioned against a time line as in Figure 1, using a sequential view in one dimension.

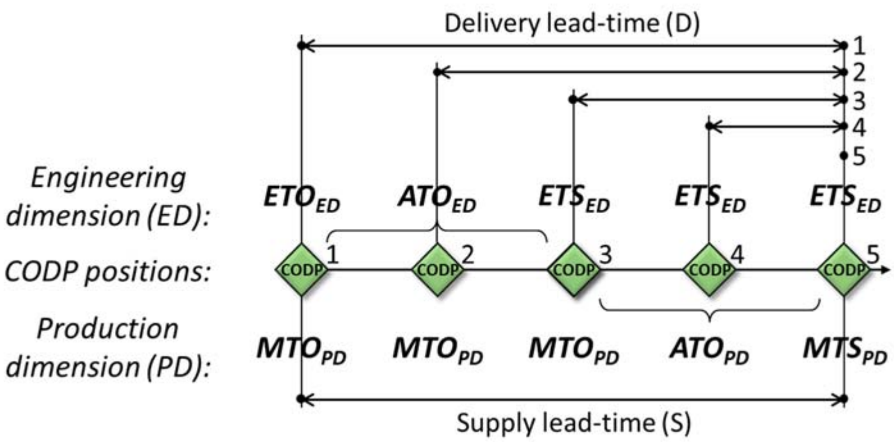

Figure 1 - A 1-dimensional typology for engineering and production (based on Wikner & Rudberg, 2005, p. 632)

The delivery lead-time (D) represents the customers' delivery requirements and the total lead-time is represented by the supply lead-time (S), also referred to as the product lead-time (Shingō, 1989). The five strategies basically represent different relations between delivery lead-time and supply lead-time. To position the sixth strategy of Table 2 (ATO_{ED}, ATO_{PD}) a 2-dimensional view is required, see Figure 2 where the green triangle is the area that allows for concurrent engineering and production. In this strategy, some engineering and production activities are based on forecasts and some are based on customer orders and involves that some production activities are started before all engineering activities are completed, i.e. based on forecasts. After receiving the customer order, the remaining engineering as well as production activities are performed based on the specific customer order. The height of the triangle is the total lead-time for the engineering activities required and the breadth of the triangle is the total lead-time for the production activities. In Figure 2, the engineering lead-time and the production lead-time have the same length, i.e. the triangle is equilateral, which is seldom the case in reality. In most cases the engineering lead-time is longer than the production lead-time. The upper right white dashed triangle is not viable since the engineering cannot be performed based on customer orders if production of the corresponding items is performed based on forecasts, see Table 2 and the reasoning around it and Wikner and Rudberg (2005) for more details.

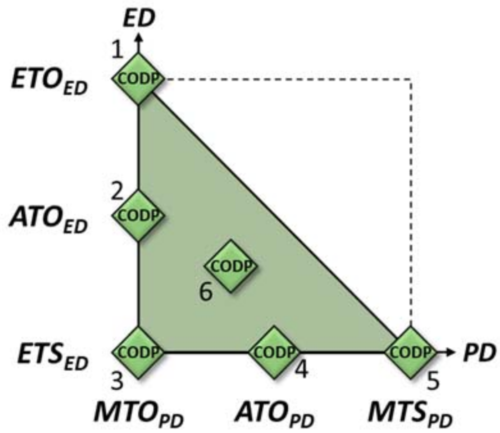

Figure 2 - The 2-dimensional CODP framework (based on Wikner & Rudberg, 2005, p. 635)

In their application of the 2-dimensional CODP, Cannas et al. (2017) introduce Redesign-to-order (RTO_{ED}) which means redesigning earlier designed products to fit a new customer order while they describe ATO_{ED} as associating a new customer order to a design not yet finalised. Here this distinction is omitted since it is difficult to make such a generic distinction and instead only the ATO_{ED} is used, which is in line with Wikner and Rudberg (2005).

Moreover, Cannas et al. (2017) introduce Finalised-to-order (FTO_{PD}) which involves procurement and production of the components partially performed before the customer order arrives, and finalised based on customer requirements. Cannas et al. (2017) interpret ATO_{PD} as assembly of the components already produced or purchased before the customer order arrives, i.e. they focus on the word "assembly" and then ATO_{PD} means that no assembly is driven by forecast but all assembly is driven by a customer order. Here, ATO_{PD} is interpreted as a strategy where some production activities are driven by forecast and some by a customer order, regardless of if these production activities involves assembly or not. They can involve procurement, manufacturing, assembly, distribution, etc, which also is in line with Wikner and Rudberg (2005).

Extending the 2-dimensional CODP

The separation of engineering and production in the 2-dimensional CODP has extended the applicability of the CODP concept considerably. Traditionally, the CODP concept has been based on the assumption that engineering always takes place before any type of production and hence e.g. MTO assumes that engineering is performed before the customer order arrives and ETO assumes that both engineering and production are performed to customer order and that engineering is performed before production. When customizations are involved this is however not as straight forward and the 2-dimensional CODP was suggested in response to these challenges. Such integrated engineering and production provides several opportunities for providing customers with customized solutions and to make the 2-dimensional CODP more versatile, three extensions are suggested below. These are: initial engineering work before production can start, the role of strategic lead-times, and separation of customization and drivers (FD/CD).

The typology and initial engineering

The original 2-dimensional CODP was developed to support adaptations to existing designs. This is based on the assumption that some kind of platform or base design is available before the adaptation can take place. The development of this platform would however be completely performed before any regular production activities can be initiated. The engineering work may of course involve some production tests, but this is assumed to be part of the engineering dimension. As a consequence, the top part of the green triangle in Figure 3 is white and dashed to indicate that during the initial product development phase it is not possible to initiate any production activities.

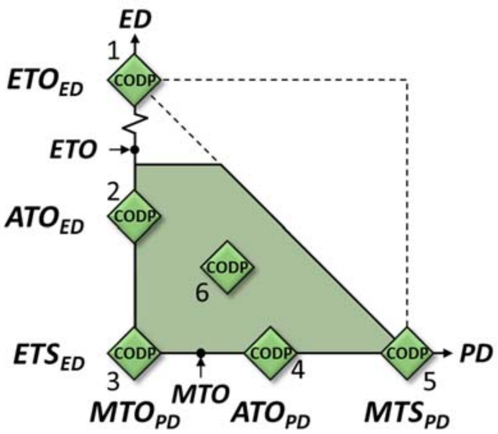

Figure 3 - The 2-dimensional CODP and initial engineering

In addition, a frequent setup is to develop generic aspects of a platform well in advance of the development of a solution based on that platform. To indicate this time-gap the ED-axis is zig-zagged to allow for the extreme point 1 (ETO_{ED}) to represent engineering work being performed far in advance. In practice, the ETO strategy seldom means designing a product totally from scratch without any former solutions to start with. Instead, existing platforms, etc., are used and based on that different new products can be developed. This is indicated with "ETO" in Figure 3. This could be compared with RTO_{ED} as described by Cannas et al. (2017), and mentioned above. However, it is a bit unclear whether RTO_{ED} includes such major adaptations to existing designs, so they could be regarded as new products, or if only minor adaptations are included.

Correspondingly the MTO strategy is frequently based on that some materials are procured before the customer order arrives and this type of MTO strategy is indicated with "MTO" in Figure 3, since the production dimension covers not only production as such but also other types of activities such as purchasing and distribution. This could be compared with FTO_{PD} as described by Cannas et al. (2017), and mentioned above, but here their clear distinction related to assembly is not used.

The typology and strategic lead-times

Strategic lead time refers to a lead-time of strategic significance and more specifically the CODP is based on the relation between the delivery lead-time and the total supply lead-time as shown in Figure 4 as a blue trajectory. The trajectory illustrates the process from start to end based on time and in terms of the type of activity being performed (ED or PD) and some additional properties, which in this case is the flow driver. The implications of the 2-dimensional CODP on the strategic lead-times have however not been explicitly covered previously. The 2-dimensional CODP is based on the separation of engineering activities and production activities but also enables an iteration between these two types of activities. Engineering and production may be performed in several phases and how this can be combined with the concept of the 2-dimensional CODP is illustrated in Figure 4. With a traditional CODP, as in Figure 1, the supply lead-time would be split into two parts, before or after the CODP. With the 2-dimensional CODP it is instead possible to identify four segments of the supply lead-time as in Figure 4. The engineering activities can take place before or after the CODP and the same is valid for the production activities. Based on these segments it is possible to define the length of the complete trajectory, i.e. the total supply lead-time as. $S = S(FD_{ED}) + S(FD_{PD}) + S(CD_{ED}) + S(CD_{PD})$ and where the delivery lead-time corresponds to $D = S(CD_{ED}) + S(CD_{PD})$. As a consequence, the segment $S(FD_{ED}) + S(FD_{PD}) = S - D$ is forecast driven and the segment $S(CD_{ED}) + S(CD_{PD}) = D$ is customer order driven. In more practical terms this could be a case where some initial engineering work is based on forecast, $S(FD_{ED})$, followed by production of semi-finished goods to forecast, $S(FD_{PD})$, and stored at the CODP in an inventory of semi-finished materials. Based on the customer order the design is adapted, $S(CD_{ED})$, and finally the product is assembled and delivered to the customer based on the customer order, $S(CD_{PD})$.

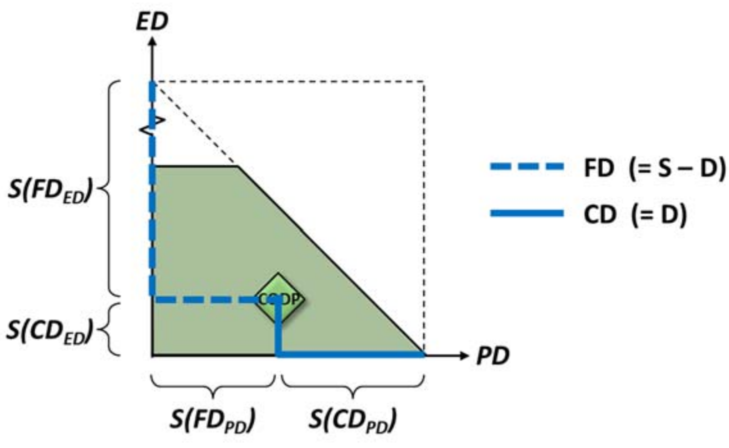

Figure 4 - The 2-dimensional CODP and strategic lead-times

The typology and customization

Customization refers to making something unique for individual customers. The concept of customization should, however, not be confused with the driver of an activity. A standardised product may be produced to forecasts as well as produced to customer order whereas a customized product only should be produced to customer order. The level of customization is therefore a separate issue compared to the driver and a separate mechanism is required. The customer adaptation decoupling point (CADP) has been suggested to actually represent the differentiation between something standardised and something customized for a specific customer order (e.g. Wikner & Bäckstrand, 2018). As a result, the CODP only distinguishes between forecast driven (FD) and customer order driven (CD). The 2-dimensional CODP is therefore extended to explicitly cover both the driver (related to the CODP) and the differentiation (related to the CADP). Figure 5 illustrates how the two different mechanisms can be combined. The dashed line indicates FD and the solid line CD as in Figure 4. In addition, colours have been added as suggested by Wikner and Bäckstrand (2018) where green represents customer generic (CG), i.e. standardised, and red delivery unique (DU), i.e. customized. The supply lead-time is therefore split into four segments with different meanings:

- Segment 1 $S(FD_{ED}; CG_{ED})$. A standard product is engineered based on forecast.
- Segment 2 $S(CD_{PD}; CG_{PD})$. The standard parts of the product are produced based on customer order.
- Segment 3 $S(CD_{ED};DU_{ED})$. The product is adapted to customer requirements through some engineering activities.
- Segment 4 $S(CD_{PD}; DU_{PD})$. The adapted product is finalised and delivered to the customer, all based on the customer order.

If the engineering activities and the production activities can be performed in parallel the trajectory could be a simultaneous combination of horizontal and vertical movements thus reducing the total supply lead-time. In this case the line would be a compromise between horizontal (from left to right) and vertical (from top to bottom) and therefore with the angle somewhere in the range of $270° \leq Angle \leq 360°$.

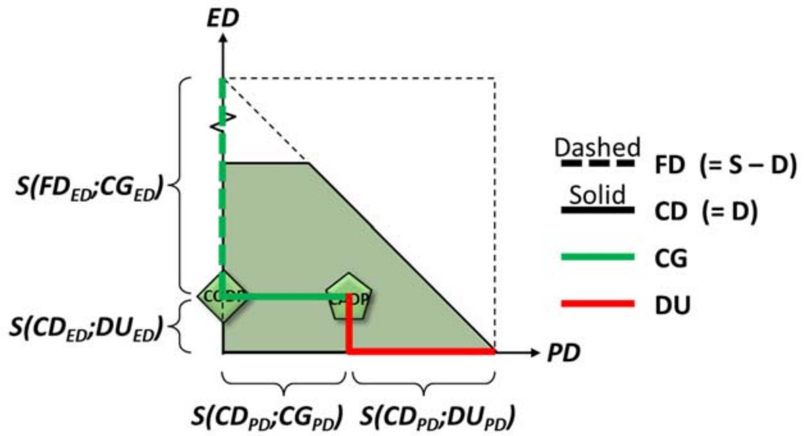

Figure 5 - The 2-dimensional CODP and customization

Empirical illustrations

The three extensions to the 2-dimensional CODP are each illustrated by a brief case.

Initial engineering

Fagerhult develops standard catalogue products based on forecasts, i.e. ETS_{ED} in Figure 3. When developing such standard catalogue products based on forecasts, the engineering process takes 12-18 months. Fagerhult also develops new customized products based on customer orders, i.e. ETO_{ED} in Figure 3. When developing these new customized products, the engineering process takes 10-20 weeks, which is very much shorter than the engineering lead-time for ETS_{ED}. However, this type of customized products builds, in one way or the other, on existing products and available solutions. In other words, the engineering lead-time of 10-20 weeks for ETO_{ED} requires that initial engineering activities have been performed in advance which is one example of the "ETO" indicated in Figure 3.

Strategic lead-times

Fagerhult also customizes standard catalogue products for specific customers with specific requirements through engineering activities, i.e. ATO_{ED} in Figure 3. These customizations are usually minor changes, e.g., change control drives or colours of a component. Although small changes, they cannot be performed through production activities, but the design engineers must be involved. Naturally, these customizations are based on customer orders and at Fagerhult the whole production of these products is also based on customer orders. As mentioned above, it takes 12-18 months for developing totally new products based on forecasts. The lead-time for the engineering activities required for the customization is around 5 days and the production lead-time is around 17 days. This means that the supply lead-time is: $S = S(FD_{ED}) + S(FD_{PD}) + S(CD_{ED}) + S(CD_{PD})$ = (12-18 months) + (0) + (5 days) + (17 days) and the delivery lead-time is: $D = S(CD_{ED}) + S(CD_{PD})$ = (5 days) + (17 days). Figure 6 illustrates the strategic lead-times for this case.

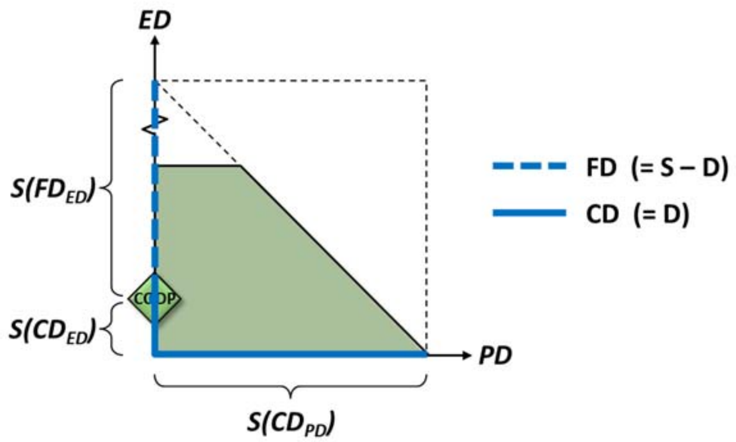

Figure 6 - Strategic lead-times in a case from Fagerhult

Customization

Siemens develops and produces gas turbines, which are built out of a core engine that is assembled with a package. The package is the customer-specific and site-specific options to be used for different applications.

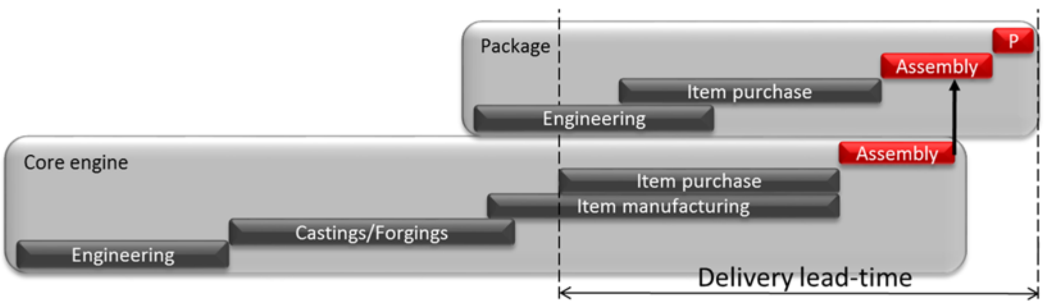

Figure 7 - A schematic illustration of engineering and production lead-times for a gas turbine. P stands for the final product, the gas turbine (based on Bäckstrand, Johansson, & Ohlson, 2014)

The core engine is engineered based on forecasts, which takes between two to six years, and production is started based on forecasts but completed based on customer orders. The package is mainly engineered and produced based on customer orders but the engineering builds, in some way, on existing products and available solutions, see Figure 7 for a schematic illustration of lead-times. This means that when a customer orders a gas turbine, the engineering and some production of the core engine as well as some engineering of the package are already performed. After receipt of the customer order, the engineering of the package is completed based on the customer specific requirements in parallel with the continuing production of the core engine as well as of the package. Siemens employs this approach and engineers the package in parallel with production in order to reduce the delivery lead-time, i.e. strategy 6 in Table 2, ATO_{ED}-ATO_{PD}.

The supply lead-time is in this case split in five segments which are described below and illustrated in Figure 8:

- Segment 1 $S(FD_{ED}; CG_{ED})$. The core engine is engineered based on forecast.
- Segment 2 $S(FD_{PD}; CG_{PD})$. Some parts of the core engine are produced based on forecast.
- Segment 3 $S(FD_{ED}; CG_{ED}, FD_{PD}; CG_{PD})$. Some engineering of the package is performed in parallel with continuation of core engine production, based on forecast.
- Segment 4 $S(CD_{ED}; DU_{ED}, CD_{PD}; DU_{PD})$. The package is adapted to customer requirements through engineering activities in parallel with continuation of core engine production, all based on the customer order.
- Segment 5 $S(CD_{PD}; DU_{PD})$. The gas turbine, consisting of the core engine and the package, is finalised and delivered to the customer, all based on the customer order.

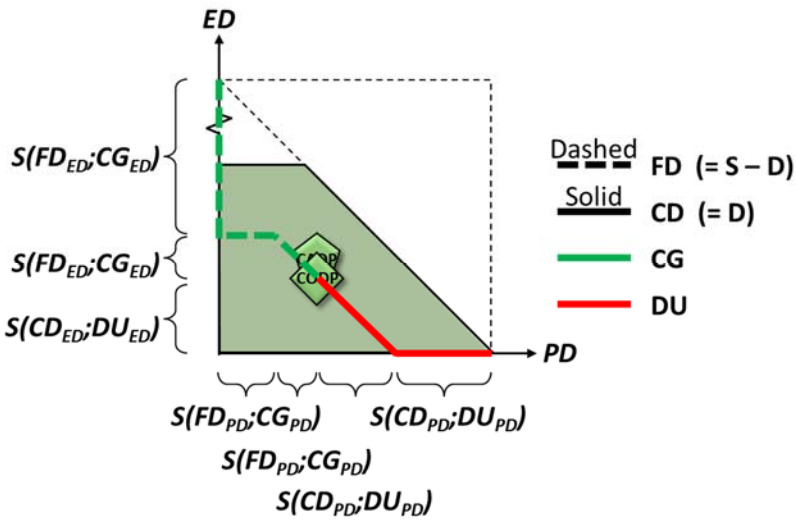

Figure 8 - Illustration of Siemens' customization of a gas turbine

Conclusion and further research

Decoupling thinking is a powerful tool that has helped companies to balance between short delivery lead-times and low inventory holding costs but mainly with focus on production and distribution. This research further develops the potential of using decoupling thinking also in ETO contexts and presents three main findings related to extensions of the 2-dimensional CODP. First, it is visualised and clearly distinguished between when engineering and production can be performed concurrently and not as well as clarified that in most cases the ETO strategy is based on an existing platform and available solutions. Secondly, strategic lead-times are examined with focus on supply lead-time, S, and delivery lead-time, D. Finally, the possibilities for concurrent engineering and production are elaborated on by introducing a more explicit recognition of customization, which clarifies different ATO situations (both ATO_{ED} and ATO_{PD}). The three findings are exemplified with empirical data from Fagerhult and Siemens.

This research, both the conceptual parts and the empirical examples, is mainly descriptive. Further research could have a more normative focus to improve practice. Moreover, further research could explore also the combination of FD and CD, to use different combinations to reduce delivery lead-time and offer more customizations.

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