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IOBPCS Based Models and the Customer Order Decoupling Point

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Abstract

The inventory and order based production control system (IOBPCS) is mainly a model of a forecast driven production system where the production decision is based on the forecast in combination with the deviation between target inventory and actual inventory. The model has been extended in various directions by including e.g. WIP feedback but also by interpreting the inventory as an order book and hence representing a customer order driven system. In practice a system usually consists of one forecast driven subsystem in tandem with a customer order driven subsystem and the interface between the two subsystems is represented by information flows and a stock point referred to as the customer order decoupling point (CODP). The CODP may be positioned late, as in make to stock systems, or early, as in make to order systems, but in any case the model should be able to capture the properties of both subsystems in combination. A challenge in separating forecast driven from customer order driven is that neither one of inventory or order book should be allowed to take on negative values, and hence non-linearities are introduced making the model more difficult to solve analytically unless the model is first linearized. In summary the model presented here is based on two derivatives of IOBPCS that are in tandem and interfaces related to where the demand information flow is decoupled and the positioning of the CODP.

Keywords: IOBPCS, CODP, System dynamics.

1 Introduction

Supply chain management, as we know it today, has developed over several decades. In the past few years, successful businesses have moved from mass-production to customisation and therefore their supply chain strategies have become more customer-driven (Christopher and Towill, 2000) or even customer-centric (Potter et al., 2015) instead of product-driven. Moreover, given the need of modern supply chains for surviving and thriving in turbulent and volatile environments caused by reduced product life cycle, increased demand for customised products and services and constant changes in the marketplace, agility became a key capability to be attained (Braunscheidel and Suresh, 2009).

On the other hand, due to pressures for leaner supply chains focus has been given to determining Minimum Reasonable Inventory (MRI) (Grünwald and Fortuin, 1992). In this way, special attention has been given to issues such as lot sizing, buffers and/or safety stock determination and improving forecasting accuracy (Dudek and Stadtler, 2005; Gunasekaran et al., 2004). To combine these seemingly contradictory developments has triggered interest in finding a competitive balance between cost efficiency and customer responsiveness (Chopra and Meindl, 2013). This balance is also known under different names such as leagility (Naylor et al., 1999) that combines lean (cost efficiency) with agility (customer responsiveness) to create a competitive whole. The interface between lean and agile in this setup is the customer order decoupling point and this is an important enabler for identifying a structural model that can be used for outlining a dynamic model suitable for dynamic analysis

In this paper we develop a production control system that combines forecast-driven and customer order-driven approaches to balance cost efficiency and customer responsiveness.

2 Theoretical framework

The objective here is to combine structural modelling for positioning of decoupling points in the flow with dynamics modelling that captures key dynamic properties of systems. Structural modelling is based on a flow perspective and on the assumption that a continuous and level flow in terms of volume and mix represent the optimal state. In practice this is rarely the case and discontinuities of the flow, related to decoupling points, introduce complexity and this is the target of structural modelling. Dynamics modelling, on the other hand, takes a certain structural model as a point of departure for investigation of dynamic properties. The outcome of the analysis may be to either change the parameters used in a certain context or actually change some structural aspects of the model, but then still within the boundaries given by structural modelling. Structural modelling hence basically identifies a number of contexts with given preconditions and dynamics modelling investigates the dynamic properties of the flow within such a given context.

2.1 Structural modelling: Decoupling points

Structural modelling based on decoupling points has been employed for decades in terms of inventory management and materials management. Particular focus on strategic decoupling points was introduced by Hoekstra and Romme (1992) in their seminal work with Philips where they outlined how to use the decoupling point that separates forecast driven flow from customer order driven flow. This strategic decoupling point was later referred to as customer order decoupling point (CODP) by e.g. Giesberts and van der Tang (1992). The location of the CODP has implications on cost efficiency (Choi et al., 2012) and supply chain integration levels (van Donk and van Doorne, 2015; Wikner and Bäckstrand, 2011). A distinction between the actual driver and information about the driver was introduced by Mason-Jones and Towill (1999) in terms of the Information Decoupling Point (IDP) which was renamed to Demand Information Decoupling Point (DIDP) by Wikner (2014) to distinguish it from decoupling related to availability of supply information such as available capacity. The relation between CODP and DIDP was investigated by (Olhager et al., 2006) in relation to the Fisher model resulting in recommendation of how to position the DIDP in relation to CODP and the concept of mediate demand. The similarities between customer order driven flow and services was highlighted by Sampson and Froehle (2006) and further developed by Wikner (2012) that identified three subsystems where the forecast driven subsystem is goods based, the customer order driven subsystem (referred to as demand driven) is service based and the consumption subsystem, finally, is driven by customer value and based on product which is a combination of goods and services, see Figure 1. As services cannot be produced to forecast the supply system upstream of the CODP only relates to goods. On the other hand, services are associated to processes that are performed to customer demand and consequently the flow downstream of the CODP is referred to as service based. The delivery lead time represents the time to execute the complete order fulfilment process and the supply lead time is the complete cumulative lead time to perform all supply activities. An important observation is that the strategic inventory positioned at the CODP represents the interface between the two supply systems and that the DIDP should be positioned upstream of that interface. In addition, the goods based system is materials focused whereas the service based subsystem is capacity focused and this is reflected in the system dynamics modelling below.

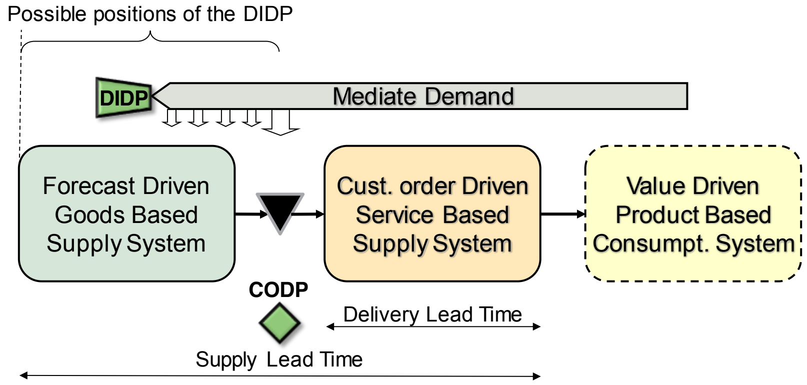

Figure 1. Framework for structural modelling using decoupling points

2.2 Dynamic modelling: Inventory order based production control system (IOBPCS)

Dynamic modelling refers to modelling that captures the dynamic properties of the flow. The original IOBPCS model (Towill, 1982) has been extended in several directions such as when also work in process is explicitly controlled. This model is referred to as Automated Pipeline, Inventory and Order Based Production Control System (APIOBPCS) (John et al., 1994) see Figure 2. This model is well recognised in the supply chain literature and has been used to investigate different phenomena, such as the bullwhip effect (Disney and Towill, 2003; Disney et al., 2004), the backlash effect (Shukla et al., 2009), the impact of production and freight capacity constraints (Cannella et al., 2008; Spiegler and Naim, 2014) and assessment of supply chain resilience (Spiegler et al., 2012).

The APIOBPCS model is basically a model of decision making and shows the impact of feedforward and feedback of information used in deciding on order rate (ORATE) to be released to production, which is represented by a lead time before the result is produced at a completion rate (COMRATE). The feedback concerns the inventory in terms of actual inventory (AINV) and actual work in process (AWIP), the latter also referred to as in the "pipeline". The key feedforward is the forecasted consumption rate (based on CONS). In addition the desired inventory (DINV) and desired work in process (DWIP) are estimated to be compared with AINV and AWIP in deciding on the ORATE released to production.

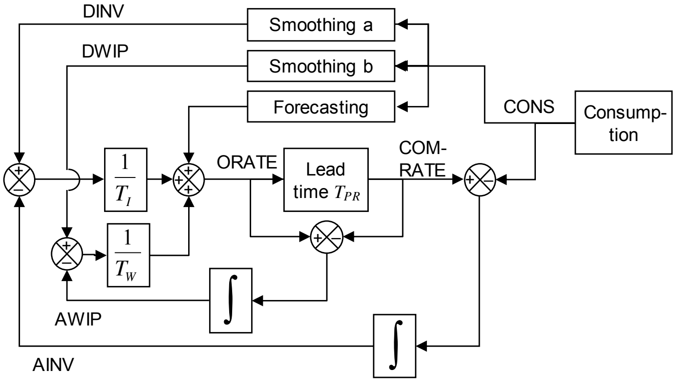

Figure 2. Framework for dynamic modelling using Automated Pipeline, Inventory and Order Based Production Control System (APIOBPCS)

An important control variable in IOBPCS is the AINV and consequently the model is usually associated with make-to-stock (MTS) scenario. If the inventory is depleted the logic is instead based on backorders which is a make-to-order (MTO) scenario. In this sense the model is a hybrid MTS and MTO system but unfortunately these two modes are not separable as only one state variable captures both the inventory on hand and the amount of backorders. Next these two scenarios are separated and a MTS model and a MTO model are derived.

3 Modelling Forecast driven supply system

The forecast driven and goods based supply system (FDGBSS) is a MTS system that produces based on forecast to replenish finished goods inventory (AINV). The model suggested here is based on APIOBPCS but modified to be suitable for a CODP-based approach. FDGBSS systems are based on material and the key interface with the customer is through the finished goods inventory. If inventory is available deliveries are assumed to take place in immediate response to CONS and in case inventory is not available, the customer requirements turn into backorders that are delivered later. This distinction between inventory and backorder is not possible to make in a linear context, such as the APIOBPCS model of Figure 2. In this model backorder is the negative inventory and a mechanism is necessary to separate the positive inventory ($AINV_+$) from the negative inventory, which with a reversed sign is referred to as the actual backorder (ABO_+).

3.1 Linear modelling of forecast driven supply system

Linear models can therefore basically only be used for FDGBSS when there are no backorders. This can be achieved by raising the DINV to such a level that no backorders occur but this would also generate high inventory levels. In Figure 3 this would mean that $A = 0$ and that the system basically would be assumed to provide infinite amount of material with no delay.

3.2 Non-linear model of forecast driven supply system

As indicated above the linear model can only be used when the DINV is set sufficiently high to eliminate the risk for backorders in relation to demand rate $DRATE_{FD}$. However, if backorders are present, the availability materials would be finite. This corresponds to when $AINV<0$ and a mechanism must be used to separate $AINV>0$ from $AINV<0$. The system in Figure 3 is based on that the orders are aiming for a balance between the actual inventory (AINV) and the desired inventory (DINV). In this case block A is the function $A = -\text{Min}\{AINV,0\}$ and basically works as a separator of AINV and ABO_+ which means that the $AINV_+$ cannot be less than zero and ABO_+ cannot be less than zero. By taking the derivative of ABO_+ the backorder rate ($BORATE_{FD}$) is obtained and it represents the change in ABO_+. If $BORATE_{FD}$ is positive the $DRATE_{FD}$ cannot be fulfilled and only part of the demand ($DRATE_{FD} - BORATE_{FD}$) can be fulfilled. When $BORATE_{FD}$ is negative the deliveries are actually greater than the $DRATE_{FD}$ and ABO_+ is decreasing. Hence the difference $DRATE_{FD} - BORATE_{FD}$ represents the actual deliveries taking place at each moment in time. The cumulative difference between $DRATE_{FD}$ and $ORATE_{FD}$ is the number of backorders at that particular moment. Note that AWIP cannot be negative even if the input is a difference between two values (rates). Since the cumulative value of what has been input is less than the cumulative value of the output AWIP can only take on positive values, unless the rates have negative values.

In summary two different material policies can be identified:

- Infinite material: No backorders.
- Finite material: Backorders are separated from inventory.

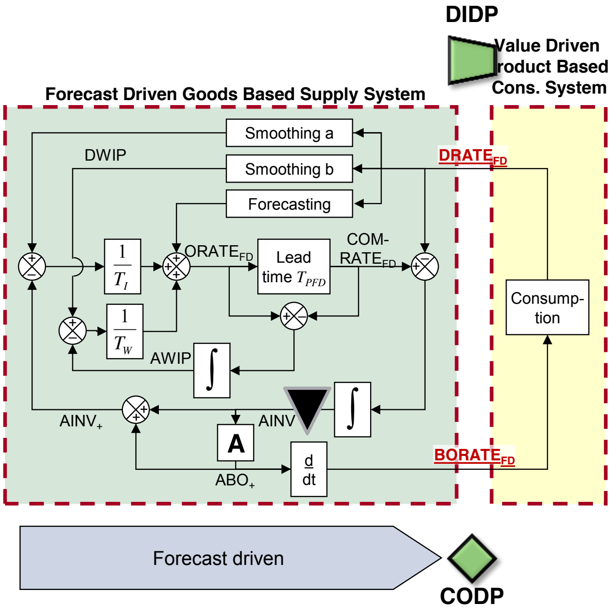

Figure 3. Forecast driven goods based supply system (FDGBSS).

4 Modelling customer order driven supply system

Customer order driven service based supply system (CDSBSS) is a MTO system whereas the original IOBPCS model is, as the name indicates, based on MTS where inventory is the key state variable. It is however possible to use IOBPCS in a MTO scenario if AINV is interpreted as a negative order book. By also removing the forecast function (setting Ta=0) the customer orders actually drives production. In addition, DINV must have a negative value representing the target order book (with a minus sign) to keep AINV negative. Few attempts have been made to extend IOBPCS model to include a MTO scenario where the activities are customer order driven. Wikner et al. (2007) developed an order book based model that required a desired order book to be set. The purpose here is to extend this work and to prepare for a CODP-based scenario. The order book *per se* is not necessary for controlling the system and instead the emphasis is on providing information on the deliveries in relation to the demand. The model will therefore be updated and instead on focusing on the actual order book the emphasis is on the deviation between the demand rate and the completion rate, i.e. the changes in the order book.

The model suggested here is capacity focused and in this sense only remotely related to the IOBPCS-family of models, which are material focused, and may hence be named Capacity Order Based Production System (COBPCS). The actual order book (AOB) consists of all customer orders received but not yet delivered to the customers. The AOB is not used in the decision logic in the model, it is only generated for other purposes. The Backlog (BL), on the other hand, consists of all customer orders that have been received but not yet released to production. The waiting time for the customer basically consists of two parts: Administrative lead time and production lead time. The administrative lead time is the delay from when the customer has released an order to when production is initiated. The production lead time is modelled using the standard assumption of (Towill, 1982), which can be interpreted as the expected dynamic behaviour of the production unit (Wikner, 2003).

The model of Figure 4 consists of two key decisions where B represents capacity management and C represents backlog management. The two decisions represents a two phase capacity strategy where the long term agility (in line with Wikner et al. (2007)) is represented by B in Figure 4 and the short term agility by C. B basically represents a lag strategy using the terminology of Hayes and Wheelwright (1984). The backlog strategy, related to C in Figure 4, represents how the backlog is handled by the system. The backlog to customers consists of three components (three different states in the model): Queue of orders not released immediately due to the capacity strategy (not enough capacity available), backlog in the system delaying release of orders, and WIP during transformation lead time.

4.1 Linear modelling of customer order driven supply system

The model of Figure 4 is linear in all components explicitly included. In addition, the capacity strategy corresponding to B is suitable for linear representation in that the response is readily represented by a first order delay. A slow response corresponds to a more level strategy and a fast response corresponds to a more agile strategy. The decided capacity is represented by the capacity rate (CAPRATE). Also the backlog strategy can be modelled in a linear fashion by assuming that a fraction ($1/T_{BL}$) of the backlog is added to the capacity available based on the capacity strategy. In this sense the orders in the backlog affect the order rate ($ORATE_{CD}$) and can be interpreted as e.g. use of over time to recover the backlog. The production lead time can be modelled as in the forecast driven model.

4.2 Non-linear modelling of customer order driven supply system

Non-linear modelling provides further opportunities to capture important characteristics of the customer order driven system. The capacity strategy can be modelled using a separate state variable for the limited capacity rate (LCAPRATE) and decide on the CAPRATE as $Min\{LCAPRATE, DRATE_{CD}\}$, which means that LCAPRATE constrains the number of orders that can be processed according to the capacity strategy. LCAPRATE is defined in the same way as CAPRATE for the linear case (a smoothed version of $DRATE_{CD}$). Also the additional capacity requirement from the backlog may be limited by CAPMAXBL which means that the additional capacity requirement from the backlog can be calculated as $Min\{1/T_{BL}, CAPMAXBL\}$. If capacity is finite without possibility to temporarily increase capacity to cover for a fraction of the backlog it is necessary to also include a capacity limit for $ORATE_{CD}$. This could be modelled by e.g. $Min\{LIMIT, ORATE_{CD}\}$ where the removed capacity requirement is returned to the OB in a fashion similar to how B is handled. This is however not included in the model of Figure 4.

In summary three different capacity policies can be identified:

- Infinite capacity (agile): No capacity limit is used in B (B=1) and all orders are delivered within the production lead time.
- Semi-finite capacity: The standard capacity of CDSBSS is finite but capacity is added to handle a fraction of the backlog.
- Finite capacity (Level): Capacity of CDSBSS is finite and a limit is applied on the capacity requirement for $ORATE_{CD}$.

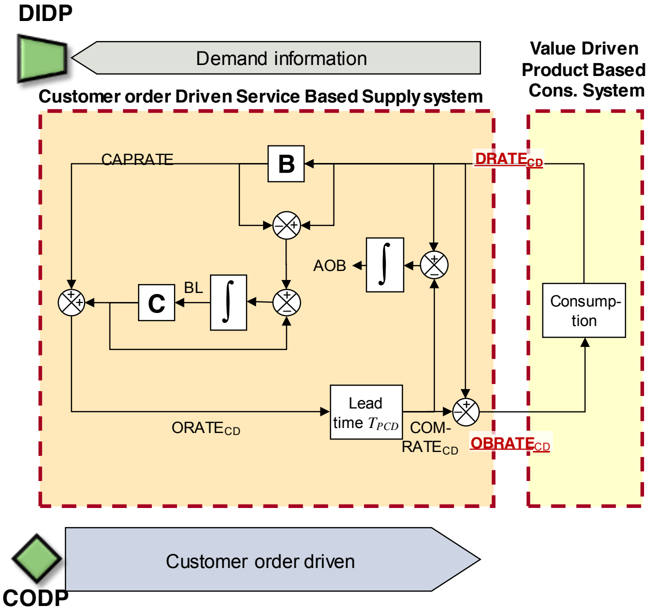

Figure 4. Customer order driven goods based supply system (CDSBSS).

5 Modelling forecast driven and customer order driven supply system in tandem

The CODP based production control system (CODPBPCS) is a combination of FDGBSS and CDSBSS. The two supply systems in tandem works as two separate entities except for when there is insufficient inventory available, i.e. backorders, in FDGBSS which then affects the receiving supply system (CDSBSS). In case of backorders the CDSBSS should be influenced in the sense that it is not possible to deliver according to the original plan and the $ORATE_{CD}$ is reduced by the amount corresponding to the backorders from the FDGBSS as shown in Figure 5 where $BORATE_{FD}$ is input to CDSBSS. The corresponding amount is also added to the backlog of the CDSBSS since it could not be produced due to the backlog. On the other hand, if the backorders are reduced the $ORATE_{CD}$ is increased by the corresponding amount and also the backlog is reduced. The availability of the demand information is represented by the position of the DIDP and two significant positions of DIDP can be identified that provides limited demand transmission or full demand transmission.

5.1 CODPBPCS with limited demand transmission

Demand information refers to information about actual sales which is here represented by customer order $DRATE_{CD}$. Information about customer order must be available for all of the CDSBSS since customer order drives that supply system. In terms of CODPBPCS this means that the DIDP is positioned between the two supply systems as shown in Figure 5. The DIDP is technically positioned at the right of the three smoothing boxes but in practice information about actual demand is not known within the FDGBSS which is only driven by forecast and the DIDP is therefore positioned between the two supply systems.

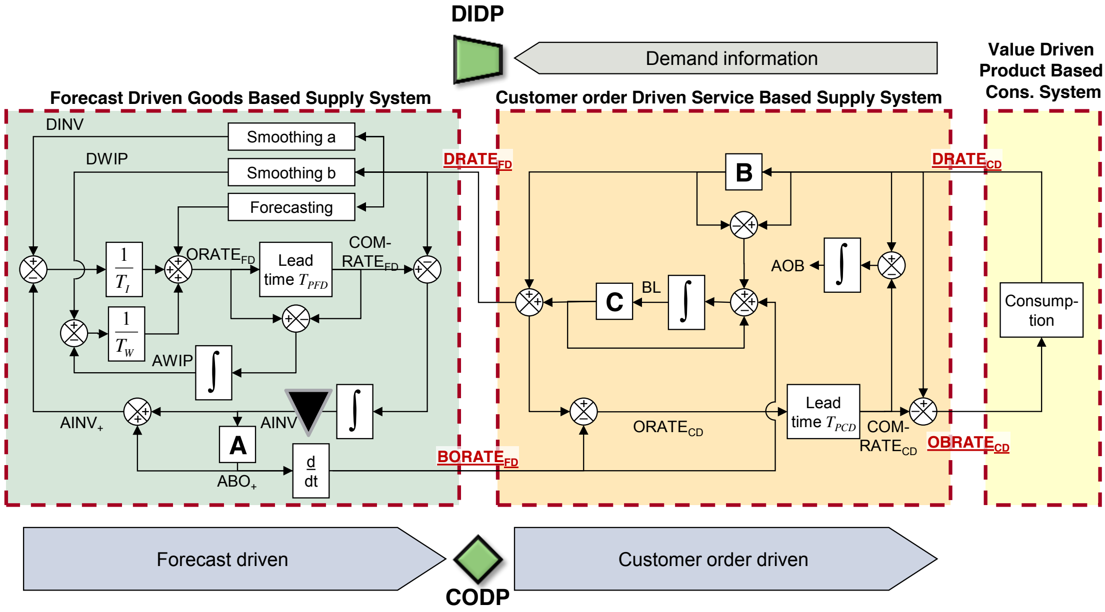

Figure 5. CODPBPCS with limited demand transmission

5.2 CODPBPCS with full demand transmission

By increasing availability of actual demand even upstream of the CODP it is possible to improve the quality of the forecast in FDGBSS. In terms of CODPBPCS the DIDP is then positioned upstream of both supply systems as shown in Figure 6. The sales information related to consumption (DRATE$_{CD}$) is made available to the FDGBSS but since the requested delivery lead time only covers activities performed by the CDSBSS the demand information cannot be used to drive the transformation directly. Instead it is used as input to forecasting (and smoothing for DWIP and DINV) resulting in a forecast based on actual market demand rather than the requirements from the CDSBSS, i.e. ORATE$_{CD}$.

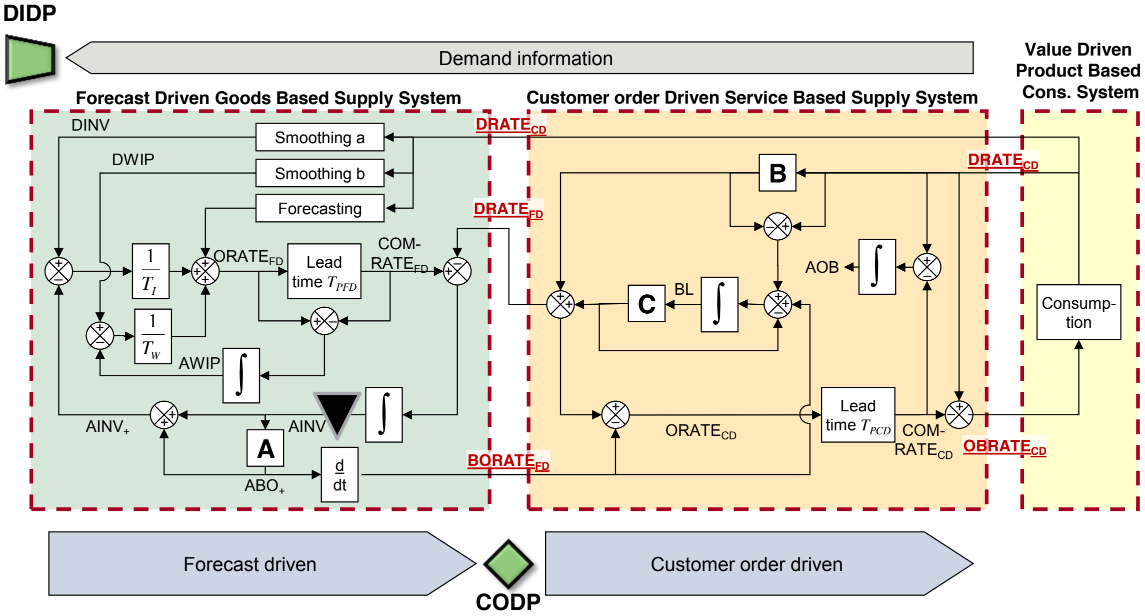

Figure 6. CODPBPCS with full demand transmission

The CODPBPCS have three different types of management decisions (A, B, and C in Figure 5 and Figure 6) that can be represented in a linear or a non-linear fashion as discussed above and summarized in Table 1.

Type of strategy	Linear model	Non-linear model
Backorder management (A)	-	$-\mathrm{Min}\{\mathrm{AINV},0\}$
Capacity management (B)	CAPRATE = Smoothed DRATE	LCAPRATE = Smoothed DRATE CAPRATE = Min{LCAPRATE, DRATE}
Backlog management (C)	$1/T_{BL}$	$\mathrm{Min}\{1/T_{BL}, \mathrm{CAPMAXBL}\}$

Table 1. Linear and non-linear versions of the three key modelling components

5.3 CODPBPCS properties

The CODPBPCS is basically a combination of two types of systems, a FDGBSS followed by a CDSBSS. As a consequence, the properties of CODPBPCS inherits the properties of each supply systems. When they are combined the FDGBSS provides materials to the CDSBSS which is capacity focused as it provides delivery to the customer within a requested delivery lead time. By combining the properties of FDGBSS and CDSBSS six different types of CODPBPCS can be identified as in Table 2 which is a combination of the conclusions from the sections above on FDGBSS and CDSBSS. Of these six intersections the models in Figure 5 and Figure 6 corresponds to FM-SFC which means finite in material, backorders are included, and semi-finite in capacity, capacity is limited for new orders but extra capacity can be added for a fraction of the backlog. In addition the extent of demand transmission can be included which would result in a third dimension of the matrix in Table 2.

	Infinite capacity (IC)	Semi-finite capacity (SFC)	Finite capacity (FC)
Infinite material (IM)	IM-IC	IM-SFC	IM-FC
Finite material (FM)	FM-IC	FM-SFC	FM-FC

Table 2. Six different types of CODPBPCS.

The CODPBPCS model is formulated in terms of production but it is important to note that it is a general model based on value adding transformation and that part of the flow is performed on speculation to forecast and the other part is performed on commitment to customer order. The actual transformation is referred to as production, above, but may concern for example administration, production, distribution or transportation and the actual value adding transformation is only modelled in terms of the lead time required to perform the transformation.

5.4 CODPBPCS and performance measures

The actual performance of the CODPBPCS system is a combination of the performance of the two supply systems FDSBSS and CDSBSS. For each supply system it is possible to identify absolut measures such as AINV and AOB to provide information about critical states (levels). In addition, relative measures relate the absolute measures to some other data and may e.g. provide info on how long the states will last. This relation between types of performance measures is based on Little's formula relating levels to time using a rate (flow measure): Time = Level/Rate. Table 3 summarizes four typical performance measures:

- Quantity based absolute measures:
  - In FDGBSS material produced but not yet sold, and hence in the actual inventory (AINV), is the most critical state.
  - In CDSBSS the customer orders not yet delivered and hence in the actual order book (AOB) is the most critical state.
- Time based relative measures:
  - In FDGBSS the actual cover time (ACT) is the AINV in relation to demand ($DRATE_{FD}$).
  - In CDSBSS the actual delivery lead time (ADT) is the AOB in relation to demand ($DRATE_{CD}$).

Type of performance measure	FDSBSS	CDSBSS
Absolute measure: Level based	AINV	AOB
Relative measure: Time based	ACT	ADT

Table 3. Absolute and relative performance measures

6 Conclusions and further research

In the derivation of the CODPBPCS we have added a new component to supply chain dynamics analysis. The Forrester model (Forrester, 1958; Wikner et al., 1991) is for example based on three FDGBSS models in tandem. In this paper we have a new type of echelon (CDSBSS) that can be used in a supply chain context where the last stage actually is customer order driven. It also means that servitization can be included and that dynamics of product-service systems can be analysed in a supply chain context. It has also been indicated that there is limited feedback between the echelons and that the main impact upstream is from feedforward rather than feedback of information. Feedforward tend to be important between echelons and feedback within echelons but more research is needed in this area.

This paper has outlined an extension of the APIOBPCS archetype where two models are used in tandem to represent a CODP based scenario. Several areas for further research can be outlined. The COBPCS in itself should be further investigated but in particular the six types of CODPBPCS models merits further research and an important venue is simulation to investigate the dynamic properties in response to e.g. step changes in demand and stochastic demand. In addition the linear approximation of the models should be investigated to show if more simplified linear models can be used for some scenarios. Finally also coverage of hybrid MTS and MTO could be investigated in light of the suggested model and the resource based customer order decoupling zone (Wikner, 2014).

7 Acknowledgements

In memory of the originator of the IOBPCS family, Prof. Denis R. Towill, 1933-2015

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