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A Typology for the Management of Engineering Activities Based on the Customer Order Decoupling Point Concept

Jonathan Gosling[1], Mohamed Naim[1] and Bill Hewlett[2]

[1] Logistics Systems Dynamics Group, Cardiff University, Aberconway Building, Column Drive, Cardiff, CF10 3EU (gosling@cardiff.ac.uk)
[2] The Costain Group, Costain House, Vanwall Business Park, Maidenhead, Berkshire, SL6 4BU

Abstract The customer order decoupling point (CODP) is commonly used to develop a simplified range of supply chain structures, ranging from standardised ship-to-stock to customized 'engineer-to-order' supply chains. This paper focuses on the latter category, with the purpose being the exploration of CODP concepts in design and engineering activities. The methodology follows a two phase approach. In the first phase, a collaborative form of inquiry as the means for producing knowledge is adopted, whereby academics and practitioners co-operated to develop a conceptual framework. The second phase includes three exploratory case studies, using interviews and site visits to gather data. The framework results in a classification of nine potential engineering subclasses. Through the exploratory case studies insight is given into the subclasses.

Keywords: Customer order decoupling point, design and engineering, engineer-to-order.

1. Introduction

The importance of product customisation has been popularised by a wide range of published work [1, 2]. Many companies have responded by seeking to develop customer driven manufacturing systems to support more tailored products and services [3, 4]. This can be done in a variety of different methods and degrees. A useful way to consider the gradations of customisation possible, developed to facilitate control over the flow of goods, is offered by the Customer Order Decoupling Point (CODP). The CODP describes the way in which orders penetrate the 'basic structure' of operations, indicating how deeply a customer order enters into the goods flow [5]. It has since been conceived of as a strategic stocking point that provides a buffer between fluctuating customer orders and smooth production output [6]. Upstream of the CODP, activities are typically speculative, aggregated and standardised; downstream of the CODP, activities are typically non-speculative (attached to known orders), individualized and customized [1, 7, 8].

Using the CODP concept, a range of structures can be defined to give a simplified classification of supply chain types. These range from very repetitive 'make-to-

stock' supply chains to very customized 'engineer-to-order' (ETO) structure [5, 7, 9] In the latter structure, each item, is, to a degree, unique, and the client will often engage with the design process [10]. Consequently, a much closer integration, and more sophisticated understanding, of the interface between engineering and the whole supply chain is needed [11, 12]. To give more refined way of understanding this interface, a small selection of papers have developed classification systems for design and engineering activities based on CODP related concepts [13-17]. The collective argument made is that orders may penetrate design and engineering activities at different points, resulting in a further spectrum of potential activities to 'decouple'. This paper refines this spectrum considerably, giving a much richer understanding of the CODP concept as applied to engineering activities.

The purpose of this paper is to add more clarity to the ETO supply chain type by identifying engineering sub-categories using the CODP concept. The specific research objectives are specified as follows:

- to develop a framework to apply CODP concepts to design and engineering activities.
- to explore the framework via a range of exploratory case studies.

2. Literature Review

2.1 The Customer Order Decoupling Point

An early article by Wemerlov [18] characterized manufacturing strategy as either make-to-stock (MTS), make-to-order (MTO), or assemble-to-order (ATO), signifying the degree of interaction with the market. MTO strategies have the highest degree of contact. At around the same time, Sharman [19] argued for the importance of the order penetration point in logistics configuration, which denotes the point at which a product becomes earmarked for a particular customer. In most cases, this point is where product specifications get frozen and the last point at which inventory is held. At approximately the same time, the seminal work of Hoekstra and Romme [5], who through consultancy work, and interaction with academics, developed an expanded and more refined discussion. They positioned the CODP as a planning and control concept, describing the way that in which orders penetrate the physical flow.

Hoekstra and Romme (1992) considered the CODP as a control architecture for the range of product-market combinations in a given product group or company. They defined five different logistics structures, including purchase to order, make to order, assemble to order, make to stock, as well as make and ship to stock. At around the same time, Konijnendjik [20] described differences between MTS, MTO and ETO situations. The risks linked to investments, lead times and estimated costs, will be different across the structures. Typically, with careful balancing, Hoekstra and Romme argued, the CODP will tend to move towards the customer as companies improve. However, the extent of this movement may depend on the nature of the market served. They further argue that the level of aggregation would depend on the specific application, but most of their discussion seems aimed at product group or value stream level. Hence, it is quite possible that companies

could manage product groups or value streams across the range of structures at any one time. It is noteworthy for this paper that the ETO situation did not feature as part of Hoekstra and Romme's (1992) classification, but was made explicit in Giesberts and van der Tang [15] and Konijnendjik [20].

The CODP was further refined by the development of the customer order decoupling zone [21]. The CODP is defined in their study as the point at which decisions are made under uncertainty concerning customer demand. Certainty may pertain to 'what?' 'when?' and 'how much?'. Using an illustrative case, they show how these aspects of uncertainty change by degrees over time, rather than an abrupt switch from complete uncertainty to certainty. To offer a more accurate representation, they develop the customer order decoupling zone to take account of changing levels of certainty over time. Research has also addressed the strategic context of the CODP [4, 22]. The influences on the optimal positioning of the decoupling point can be complex when positioned within the strategic context. Olhager [7], expanding the early work of Hoekstra and Romme (1992), suggests market, product and production related factors all interact to give an optimal decoupling positioning.

A different but highly relevant stream of literature relating to the customisation and standardisation of different work activities began to develop alongside the CODP literature. Lampel and Mintzberg's [1] seminal paper on the nature of customization blazed a trail for many papers in this area. Based on the logic of aggregation and the logic of individualization, they develop a continuum of strategies to explain how standardization and customization may interact for different elements of a manufacturing process. Although the language and intellectual material used to develop the continuum is quite different, there is much crossover between the structures defined in Hoekstra and Romme (1992) and Giesberts and van der Tang [15]. Later the two literature streams became more integrated to consider mass customisation, as shown in Rudberg and Wikner [8]. In this paper we consider that the CODP is both the point at which the customer order initiates activities, and which then leads to a path of subsequent activities which become customized.

2.2 Engineering Management and the Customer Order Decoupling Point

The scoping of this paper is primarily aimed at the ETO supply chain, where all production dimensions are customized for each order and there is some degree of engineering work [10, 23]. While this focus gives a clear boundary, the degree of engineering work involved within this production situation lacks clarity. A range of studies that explicitly discuss engineering activities within the CODP context is shown in table 1. This helps to give a sense of the potential spectrum of potential situations, and builds a foundation for later elements of the paper.

Within the construction management literature Winch [16] distinguishes between production information flow and material flow, suggesting that production information flow can be divided up into concept to order, design to order and make to order strategies, thereby offering potential ETO subclasses. A different approach

was proposed by Giesberts and van der Tang [15], who indicated a potential separation of production and engineering order points, rather than a linear approach. Wikner and Rudberg [13] expand this line of argument, giving detailed models for the decoupling of engineering and production related activities of the supply chain. An engineering dimension and production dimension are advocated with the engineering dimension ranging from ETO, where a new product is designed, and engineer to stock (ETS), where a design is already 'in stock'. Between ETO and ETS engineering modifications to existing product designs are used in varying degrees.

<table>
<tr><th>Wikner and Rudberg [13]</th><th>Giesberts and van der Tang [15]</th><th>Dekkers [14]</th><th>Amaro et al. [24]</th><th>Winch [16]</th></tr>
<tr><td rowspan="4">Engineer-to-stock</td><td rowspan="4">Standard</td><td>Transfer production instructions</td><td>Take existing design</td><td>Make to order</td></tr>
<tr><td>Transform standard information</td><td>Pick from set of options</td><td rowspan="2">Design to order</td></tr>
<tr><td>Adaptation of existing configurations</td><td>Modify existing design</td></tr>
<tr><td>Total dedicated design</td><td>Produce new design</td><td>Concept to order</td></tr>
<tr><td>Engineer-to-order</td><td>Customer Specific</td><td></td><td></td><td></td></tr>
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Table 1: Categorizations of design and engineering activities in the CODP literature

Dekkers [14], perhaps giving the most comprehensive account of the CODP as applied to engineering activities, distinguishes between the customer order entry point and the order specification entry point. The former relates to the point where an order enters the material flow, whereas the latter relates to the order entry point within engineering work. Four different order specification entry points are identified, ranging from a total dedicated design to standard designs. Both Wikner and Rudberg [13] and Dekkers [14] explore the way in which production and engineering points interact. In a more recent comprehensive review, Dekkers et al. [11] re-emphasize the lack of research to enable further understanding of these interactions since these papers were published. Further potential design and engineering categories are given in Amaro et al. [24]. Gosling et al. [17] consider engineering dimensions in the context of the potential for research and development activities may be performed to order as part of engineering work. They link 'research to order' activities with Technology Readiness Level scales, developing a scale of potential points in the engineering process.

3. Research Methodology

Ottoson and Bjork [25] argue that when dealing with complex adaptive systems, such as engineering and product development projects, researchers should consider 'insider' and 'participatory' approaches to research. A co-operative form of inquiry as the means for producing knowledge is adopted herein. In such forms of inquiry the roles of researcher and 'subject' are reconsidered, and research is done with people and not on or about them. The researcher(s) and 'subject' jointly conceive, design, manage and undertake the research [26]. Thereby, those who might otherwise be subjects of research are to a greater extent engaged as inquiring co-researchers [27].

Figure 1 summarizes the overall approach. As can be seen, co-operative inquiry is used as an overarching approach to conceptual development. Within this there is an exploratory case study phase. Conceptual development was facilitated through, presentations face to face meetings, teleconferences and email exchange. This led to an iterative process of conceptual development, cycling between the experience of industry professionals and researchers, with reflection on relevant literature and practice. We argue that this approach offers a well-rounded and informed approach to framework development, capturing a range of perspectives and feedback prior to wider case study methods being employed.

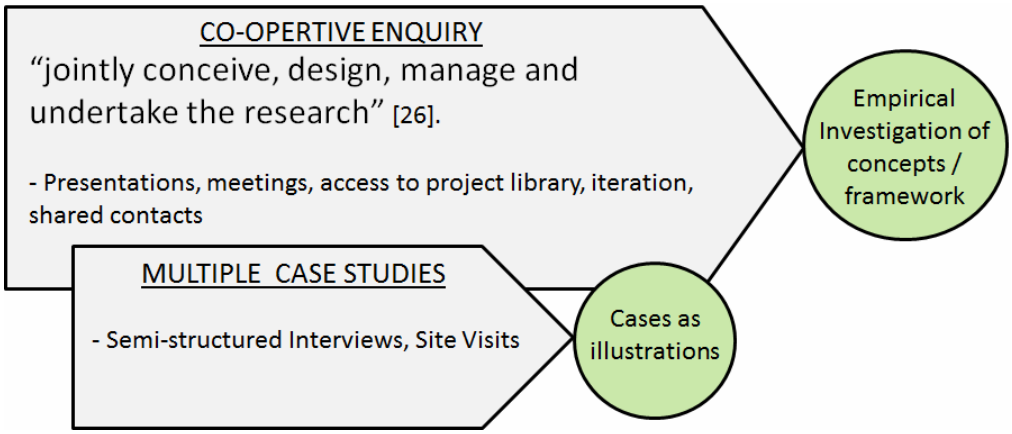

Figure 1: Visualization of method

The cases are intended to be exploratory, helping to develop theory and illustrate the categories developed during the conceptual phase. Cases should be purposefully selected to best illuminate the phenomena under scrutiny [28, 29]. In this study, the characteristics of the ETO situation were purposefully sought: products and projects with a degree of engineering in new orders. This paper includes three exploratory case studies, each chosen to represent one of the main subclass groups represented in the framework developed later in the paper. Each case involved interviews that followed a semi-structured protocol, as well as a site visit. The three case studies give examples from rail infrastructure, bridge and telescopic lenses sectors. Questions sought to relate specific projects to the framework, leading to a detailed discussion of the amount of novel engineering

work undertaken, the amount and type of work undertaken speculatively, and the type of activities performed 'to-order'. Interviewees included the Research and Development Manager (Project 1), Project Manager and Technical Director (Project 2), Structural Engineer (Project 3).

4. A Classification of Engineering Decoupling Points

The logic for the application of the CODP to engineering activities is shown in figure 2. It shows generic activities in a supply chain, and the extent of penetration of the CODP (the line indicates that all generic activities are customized for each customer order). It also indicates that the design activities of the engineer to order activities can be subdivided into three broad categories: research, code and standardized. These, in turn, can be further refined to give 8 engineering 'subclasses'. These provide a basis for considering the level of customization and standardization in design activities, as well as considering those activities that are speculative and those that are performed to a specific customer order.

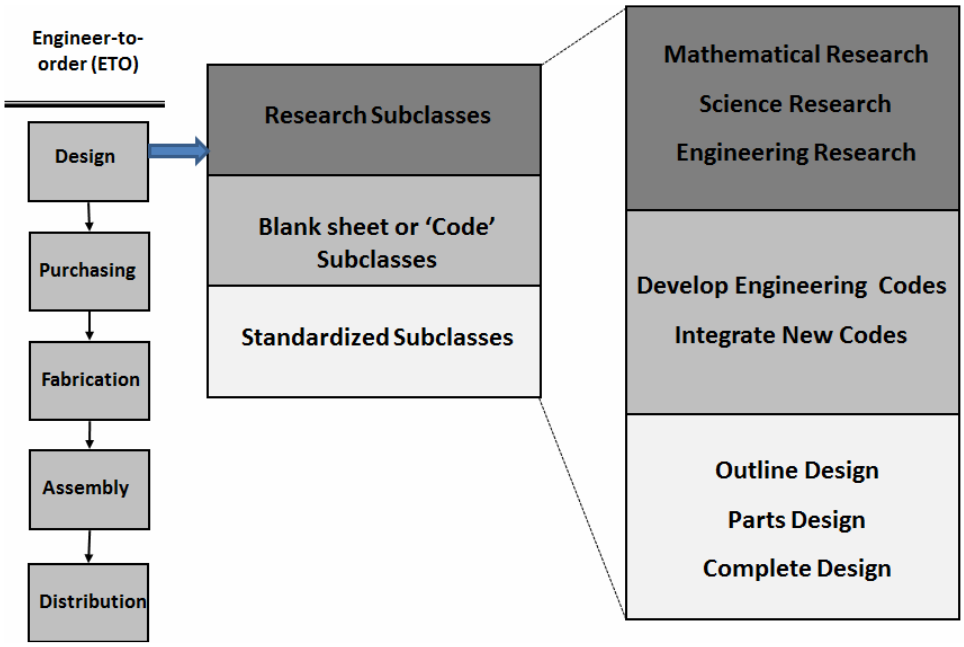

Figure 2: 'Unpacking' of the engineer-to-order supply chain (Adapted from [17])

The framework developed, based on the 8 aforementioned subclasses is shown in figure 3. This continuum gives 9 potential structures for controlling the flow of design and engineering activities. These are now described in turn. In the research subclasses, research and development is performed 'to-order'. This may include proof of concept, testing, or even fundamental research to establish principles for a final solution. The first subclass within this category is Mathematical Research. In this subclass, the theoretical principles are unclear, and it is not even obvious that

a solution exists at all. The second type of subclass within this category is Science Research. In this subclass, the theoretical foundations are likely to exist in principle, but the application is uncertain. A further subclass within this category is Engineering Research. In this subclass, testing of materials, principles or applications is required. Petroski [30] offers a useful distinction between science and engineering: “design and development most distinguish engineering from science, which is principally concerned with understanding the world as it is” ([30] p 2).

The next category is the code subclasses. These relate to those subclasses that require some interaction with an established set of codes or codified knowledge. In this set of subclasses, the purpose of the project can be defined, but there is an open brief as to the solution. Typically the majority of the solution can be designed and delivered without the need for research activity. The term accepted codes is used to signify the use of an established body of engineering knowledge, which is recognised and drawn up into a readily available set of codes for a given community to use. Adapt codes is the first subclass in this category. Following engineering testing and research, codes would have to be developed and to articulate any new standards. Adaptation work may have to be undertaken to take test results and integrate for a specific, integrated solution. In the second subclass, new codes would have to be integrated with existing codes for more general market acceptance. The second subclass in this category is integrate codes.

In standardized design subclasses, the principal challenge is to bring this standard knowledge together for the needs of a particular project. For example, the form, layout and integration will need to be considered on an order by order basis. In the *configure design* subclass, accepted codes are used as the bases to develop outline designs. This relates to what has been described elsewhere as establishing project design rules [31], enough is known about the engineering codes that the design can be prepared in outline by an 'experienced eye’. A professional design engineer can then work up the design as outlined within the parameters predicted. The next subclass is *adapted design*. In this situation, individual parts of the design may be customized on a project by project basis, but the overall design rules have been established. *Finalise design* is the next subclass in the classification. This assembles existing components for a particular solution. The design solution is built up from an established set of parts, each with known characteristics and with the rules for overall configuration being set down. The final subclass is *complete design*. Here, designs are completed, standard products that are perfectly adapted to requirements. At this point, the state is similar to ‘buy to order’ structures with ETS designs, as described in production decoupling point classifications [5].

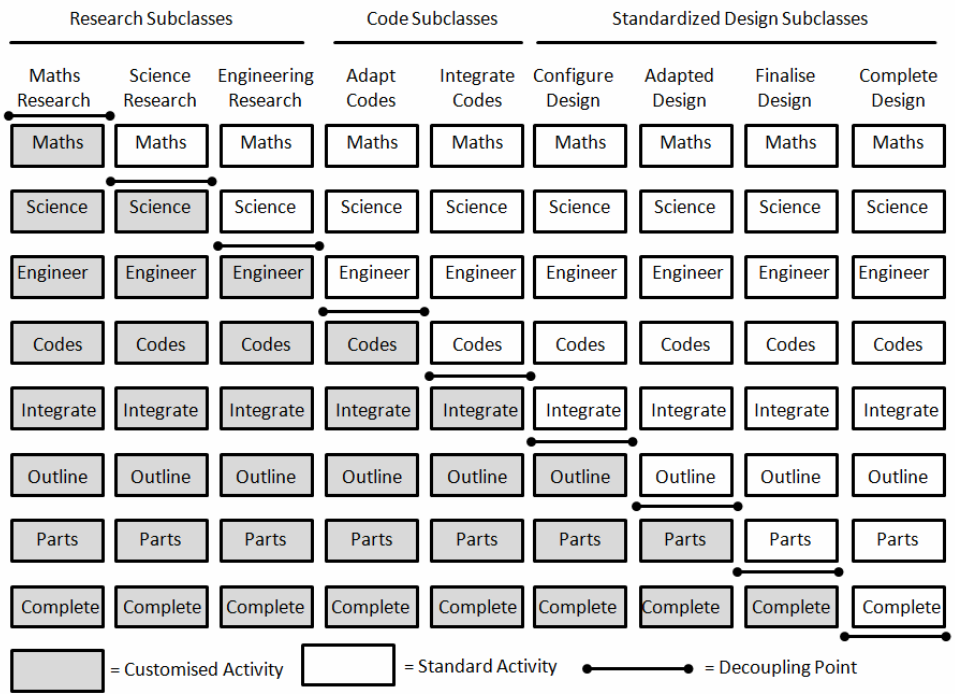

Figure 3: Continuum of Engineering Categories and Subclasses

5. Illustrative Case Studies

Table 2 gives an overview of the cases used to illustrate the three main subclass groups in the framework, and gives an insight into the nature of speculative engineering work held at the CODP before a specific customer project was started. The latter helps to give insight into the nature of the 'starting point' for different subclass categories. This will be discussed further below.

Project 1 exemplifies the *research* subclasses shown in the framework. It relates to a project to develop the next generation manufacturing technology for large scale optics. A group of research and development companies were commissioned to undertake a manufacturing feasibility study to provide the mirror component for a large scale telescope. Although the feasibility study is limited to 7 segments for the mirror, the complete mirror for the telescope is estimated to comprise over 1000 hexagonal glass segments each measuring around 1.5m. The project makes use of a new process, and new developments in nanotechnology, so that the surface of each segment is polished to an extremely well defined profile within close tolerances. It is a very experimental set up, bringing together scientists and bespoke technology. The polishing and smoothing process involved is experimental, and the principal challenge for the project is attempting to prove to the customer that the solution is possible. Prior to the feasibility study, the principle mature of the knowledge held 'in stock' was research paper relating to polishing

processes and polishing technology relating to similar sectors. The company heading the consortium also specializes in managing innovative consortium, and therefore held contacts and know how in relation to managing innovative new projects.

Project	Sector	Detail	Subclass Category	Held at CODP
1	Telescopic Lenses	Prototype of hexagonal mirror segments for a large telescope	Research	-Research papers -Experiment results -Managing Innovation
2	Infrastructure – Rail	Redevelopment and enlargement of major London Station	Code	-Existing rail standards and codes -Sector expertise and investment in innovation culture.
3	Infrastructure - Road	Bypass scheme access bridge	Standardized	-Bebo Bridge System

Table 2: Illustrative Case Studies for each of the major subclass groups

Project 2 offers an example of the code subclasses. This refers to a significant redevelopment of a major London train station, which includes significant engineering and construction work for station buildings, bridges, platforms, as well as power and plant rooms. The building and platforms are subject to heritage regulations. Innovative engineering solutions were required while working with the existing Victorian fabric, for example restoring traditional brick arches, which are rarely used in modern construction. Working with existing fabric, and the uncertainty of the London underground called for innovative adaptation of accepted codes, as well as bringing the station into compliance with Network Rail standards and codes. These requirements provide guidance directed towards securing the safety and efficiency of rail infrastructure, as well as compliance for interoperability and domestic legislation. The main contractor has invested heavily in innovation management, developing an area of the business to manage it, as well as developing sector expertise in station refurbishment.

Project 3 gives an illustration of a *standardized design* subclass. This case profiles an arch system bridge within a bypass scheme in South Wales. The bridge was based on a Bebo arch system standard design. The system articulates construction standards and procedures to follow, which extend to fabrication, handling and transportation, construction and installation, backfilling and

inspection. A major feature of the Bebo system design is the arch elements. These are pre-cast from a standard mould. These were originally developed by Swiss Engineer developed in 1965, and first built in 1967. Over 800 have now been built, conforming to a wide range of codes [32]. Standards are specified for the casting, lifting, storage and haulage of the arches. The system also incorporates standard interfaces for 'stitching' the arches together. The particular design employed in the project incorporated 22 pre-cast arches to span the bypass. The outline design had to address a number of design challenges and adaptations. The use of bevelled tunnel endings, rather than square, which was favoured by the client, as well as challenging slope of the site, meant that integrated codes had to be cleverly incorporated into the design solution. The main contractor was supported by consultants from the BEBO licensing arrangement.

6. Managerial Implications and Future Research

A range of publications have espoused the importance of alignment of strategy with structure or situation [6, 33]. We extend this argument to engineering subclasses. A great many best practice approaches are likely to be similar across the aforementioned subclasses, but similarly some will require tailoring to the amount of engineering work required. That is to say that different subclasses, or groups of subclasses, may require different thinking. By being developing a framework to categorize project complexity, this paper opens up the potential for using this as a basis for tailoring approaches. One such dimension is contracts. Unsuitable contracts have long been found to allocate risk inadequately among the supply chain [34], and this can lead to payment conflict, delays, quality conflict and administrative conflict [35]. Hence, a contractual and strategic fit with the type of subclass is envisaged.

7. Conclusion

This paper has investigated the application of CODP concepts to design and engineering activities, and the potential for using this as a basis for tailoring approaches adopted. The methodology was divided into two parts. The conceptual development, which was undertaken in co-operation with practitioners, represents the first part; exploratory case studies represent the second part. A framework was developed to apply CODP concepts to design and engineering activities, resulting in nine engineering subclasses. This offers practitioners and researchers a simplified way in which to classify the extent to which engineering activities are carried out under uncertainty. The continuum developed raises the interesting possibility that research might have to be undertaken 'to-order' as part of an ETO project, an area that has received little discussion in the literature. In doing so, this paper refines existing research in this area, as well as extending the application of CODP concepts, and adds more clarity to the ETO supply chain body of knowledge. The framework and strategies were explored via a range of exploratory case studies. Three case studies were analyzed and described. These were classified along the spectrum of subclasses developed to illustrate different structures within the framework. A cautionary note must also be added in terms of

the generalizability of findings. The study is based on a limited number of cases and sectors and care should be taken in applying the framework developed in new contexts.

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