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**18th ICPR paper: Engineering Management and the Order Entry Point**

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# Engineering Management and the Order Entry Point

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## ABSTRACT

Traditionally, most literature has focused on the impact of Order Entry Points on manufacturing and logistics. Current literature about these entry points undervalues the effects on the engineering process and the writings on modular design hardly discuss the relationship with operations management. To assess and review the consequences for engineering management, a framework has been developed based on earlier research, covering the standard working methods for the conversion of customer requirements into components of a modular product architecture, the management of customer order activities and the separate development of new product architectures for future demands.

Five case studies served as base for the investigation of engineering management. Although it might be expected that operations management for the engineering process should not differ from that of manufacturing, the case studies prove otherwise. The characteristics of engineering activities allow a more limited range of interventions, putting more stress on adequate capacity management. Additionally, the implementation of modular design does create sometimes resistance to change. Strategically, modular design has the advantage of architectural innovation. However, the implementation of the Order Entry Matrix in engineering management shows that control of engineering activities is weakly developed in industry.

**Keywords:** Order Entry Points, modular design, engineering management, customisation, architectural innovation

## 1 INTRODUCTION

With the industrial focus shifting to a lapse in productivity, while decreasing the integral lead-times and offering a larger variety of products, the drive for integral approaches toward operational management increases. Many companies still struggle to meet these often-conflicting requirements (the trade-off is discussed by Andries & Gelders [1995, p. 31]) and find themselves confronted with the question how to organise their processes. The fulfilment of customer demands often ends in longer lead-times and higher costs to design and manufacture dedicated products caused by the impact of the specific requirements on the total configuration of products. Alternatively, a tendency of standardising products will hand over orders and clients to the competition, due to its inherent cost and inflexibility. Companies have no choice but to meet simultaneously the requirements for product flexibility, lead-time and productivity. Especially, since the future demands on the performance of an organisation will result into further integration of sales, engineering and manufacturing, according to Furukawa (1993).

A workshop in June 2004, organised by the Dutch Ministry of Economic Affairs and attended by both practitioners and academics, highlighted the continuing industrial need for integral approaches towards design, engineering, manufacturing and logistics to meet the changing requirements of contemporary markets. Management research has already generated integral approaches to cope with the conflicting requirements of productivity, lead-time and variety; especially, the concepts for the Order Entry Points and modular design address these industrial challenges. The Order Entry Point is also known as the Customer Order Decoupling Point (by most authors), while some call it the Order Penetration Point (Sharman, 1984) and Sabri & Beamon (2000) label it the Product

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4 Configuration Point; Order Entry Point seems a more appropriate term in this respect.  
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6 According to these approaches, management should consider the decisions for positioning  
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8 the Order Entry Points to meet performance requirements adequately, often in combination  
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10 with modular design.  
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### 13 **1.1 Background**

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15 Most literature pays attention to the impact of the Order Entry Points (and the related  
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17 modular design) on logistics and operations. Originally, Sharman (1984) introduced the  
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19 Order Entry Points for logistic control and Wemmerlöv (1984) pointed to the existence of  
20  
21 different modes of operation for Make-to-Stock, Make-to-Order and Assemble-to-Order.  
22  
23 These writings were quickly followed by others, like Hoekstra & Romme (1985), explicitly  
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25 introducing the Order Entry Points to improve logistic management in industrial  
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27 companies. Meanwhile, it has been developed to address logistic management (e.g.  
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29 Christopher & Towill, 2000; van Donk, 2001; de Haan et al., 2001; Vries et al., 1999;  
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31 Wanke & Zinn, 2004), Supply Chain Management (like Croxton et al., 2001; Graves &  
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33 Willems, 2000, Lee & Lau, 1999; Mason-Jones et al., 2000; Sabri & Beamon, 2000), IT  
34  
35 applications (for example, Andries & Gelders, 1995, p. 36; Giesberts & van de Tang, 1992;  
36  
37 Sabri & Beamon, 2000), and outsourcing (e.g. van der Vlist et al., 1997). A stream of  
38  
39 literature sees Order Entry Points as concept for connecting the lean paradigm with the  
40  
41 agility of the supply chain (Christopher, 2000; Naylor et al., 1999). Others, like Mason-  
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43 Jones et al. (2000) and Schuh et al. (1998), emphasise the strategic flexibility of modular  
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45 designs connected to the Order Entry Points; this flexibility has also been a cornerstone for  
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47 literature on product families and platforms (like Meyer & Utterback, 1993). Generally  
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4 speaking, much emphasis is given to consequences for order processing, stock control,  
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6 stock replenishment and performance improvement.  
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10 But what about the modular design and its link to engineering management? Within the  
11  
12 strand of literature on logistics and Supply Chain Management, the modular design is  
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14 mostly taken either as starting point or as consequence of the Order Entry Points (e.g.  
15  
16 Mikkola & Skjøtt-Larsen, 2004). While at the same time, most literature on modular design  
17  
18 (e.g. Sanchez, 2004; Simpson et al., 2001; Stone et al., 2000) does not include  
19  
20 manufacturing strategy or logistics as driver for the configuration of products. Riedel &  
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22 Pawar (1998) highlight that the concepts of design and manufacturing are not linked in  
23  
24 literature and that the interaction of product design and manufacturing strategy is under-  
25  
26 researched. Spring & Dalrymple (2000) come to the same conclusion when examining two  
27  
28 cases of product customisation: manufacturing issues get little attention during design and  
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30 engineering. The initial case study resulting from Action Research into Strategic Capacity  
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32 Management (Dekkers, 2003) demonstrates this notion as well. For the Order Entry Points,  
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34 Rudberg & Wikner (2004) distinguish the engineering and production dimension in their  
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36 conceptual paper, while earlier work by Bikker & Dekkers (1994) elaborates on the  
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38 consequences for engineering. Consequently, most literature has ignored the vital link  
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40 between engineering processes and manufacturing strategy and hardly discusses the impact  
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42 on operations management of engineering.  
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## 50 51 **1.2 Research Methodology**

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53 In this context, five manufacturing companies have been examined on the impact of Order  
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55 Entry Points; the scope did include manufacturing management and engineering  
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57 management (product development in these companies has been embedded in the  
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4 engineering department). The theory of modular design leading to a coherent approach to  
5 product architectures originates from earlier research (Bikker, 1992; van der Sterre, 1992).  
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9 Logistic implications and a proposal for control have been discussed in Dekkers & Sopers  
10 (2001). The earlier research shows the successful implementation of the concept though it  
11 implies that companies have to adapt their operation's practices and systems. Action  
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16 Research in all five case studies – with the findings in separate reports - revealed that a new  
17 organisational structure with upstream Order Entry Points would prove beneficial.  
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21 However, it remained unclear which impact these Order Entry Points would have on  
22 control of engineering to meet customer demands and therefore this has been examined  
23 separately (this was one of the remaining research topics mentioned by Bikker & Dekkers  
24 [1994]). Nonetheless, engineering management cannot be separated from the  
25 implementation in manufacturing and logistics. Hence, the issues for engineering  
26 management have been extracted from the reports of the five case studies. Since each case  
27 study contains unique solutions, the research reported here focuses on commonalities with  
28 respect to issues in engineering management; additionally, the subject of integration of  
29 sales, engineering, manufacturing and logistics has been reviewed.  
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### 44 **1.3 Scope of Paper**

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46 Consequently, this paper will address the link between engineering (including product  
47 development) and manufacturing strategy and it will discuss the impact of the Order Entry  
48 Points on the operations of engineering. This way it will connect modular design as an  
49 engineering concept to the Order Entry Points. The publication will also provide a  
50 framework for engineering management based on the Order Entry Points. Furthermore, it  
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4 will analyse the issues related to the implementation in engineering management. The  
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6 added value is the disclosure of a field not well-studied in literature.  
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10 The paper will start with a description of the processes within industrial companies,  
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12 directed at the engineering and manufacturing processes. Section 2 links these processes to  
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14 the Order Entry Points mainly based on the previous publications, which relate closely to  
15  
16 other literature in this field; however, the benefit is the distinction of Order Entry Points for  
17  
18 both production and engineering processes. For some readers these theories might prove  
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20 common ground. Section 3 introduces the theoretical framework for engineering  
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22 management by the link to the Order Entry Points. This section presents the five case  
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24 studies conducted within this framework and reports on the findings of the research into  
25  
26 engineering management. Section 4 concludes the paper and displays the recommendations  
27  
28 following from this research, which enables companies to cope with the contemporary  
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30 challenges for performance and strategy more effectively caused by the trends of increasing  
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32 variety and customisation.  
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## 39 **2. ORDER ENTRY POINTS**

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41 That the current trend of customisation affects the control of operations within industrial  
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43 companies leaves no doubt. Lampel & Mintzberg (1996) demonstrate the change of the  
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45 demand by clients and the penetration of this demand into the organisation. Child et al.  
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47 (1991) note that in some cases, companies attribute as much as 30% of their costs to  
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49 product variety, while these variations account for as little as 3% of sales. Wüpping (1998)  
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51 notes that especially during difficult times companies tend to accept any customer  
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53 requirement not to leave any space to competitors. This illustrates the impact of the  
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55 strategic choice on the performance of companies with the continuum of strategic choice  
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4 ranging from pure standardisation to pure customisation. Pure standardisation leaves no  
5 room for differentiation, segmented standardisation may provide different distribution  
6 services or channels to different customer segments, customised standardisation  
7 encompasses final assembly of modules according to specific customer requirements,  
8 tailored customisation includes customer-specific components and modules in the final  
9 assembly, and pure customisation covers all specific process to meet unique customer  
10 requirements. According to Lampel & Mintzberg (1996) these five types, especially the  
11 trend for standardised customisation, effects the way anyone looks at organisations and the  
12 control of the primary process.  
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26 [Insert Figure 1 about here]  
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29 Figure 1 describes the design processes, engineering processes and manufacturing  
30 processes; it distinguishes two main processes: the product information flow and the  
31 material flow. During the product information flow, client requirements transform into  
32 specifications and instructions for manufacturing. The material flow concerns the  
33 manufacturing of parts and the assembly of the final products from parts and purchased  
34 parts. The *Sales Process* of this model translates the client's requirements into  
35 specifications for engineering. The sales process is not only performed by the sales force  
36 but might involve other personnel, such as sales engineers, project engineers, engineers and  
37 technical buyers from the customer. The *Engineering Process* transforms the specifications  
38 from the sales process into standards and information for production, i.e., drawings,  
39 assembly instructions, etc. Before using these standards and information, the manufacturing  
40 engineering function adds production instructions for the actual production process. The  
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4 *Manufacturing Process*, including purchasing materials and parts, converts these materials  
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6 and parts into products ready for distribution and delivery.  
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10 When the delivery times for a company decrease, the turnaround for logistic control arrives  
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12 if the lead-time for delivery of specific orders approaches or becomes shorter than the  
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14 throughput time for engineering and manufacturing. Especially in the case that clients  
15  
16 require specials or specific requirements, they have a few options for the product  
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18 information flow and the material flow. For the product information flow, companies might  
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20 reduce further on lead-time through:  
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- 23 • introducing new methods of working;
  - 24 • concurrent and simultaneous engineering;
  - 25 • reuse of constructions.
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33 The introduction of new methods, concurrent and simultaneous engineering will not always  
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35 have the desired effect. The options will reduce delivery time but they approach the specific  
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37 client requirements from a project-oriented point of view (Dekkers, 1997). The reuse of  
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39 constructions makes it possible to apply already developed components and assemblies for  
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41 a new client order.  
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## 45 **2.1 Order Entry Points**

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51 [Insert Figure 2 about here]  
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54 Within the material flow companies have only as an option to manufacture on stock,  
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56 located on an appropriate point within the manufacturing process. This point of stock is  
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4 called the Custom Order Entry Point. The point where an order enters the material flow, the  
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6 Custom Order Entry Point (COEP), determines which specific activities have to be  
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8 undertaken after the start of a custom order (Figure 2); please note that the points of stock  
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10 have been omitted from the figure. Although instructions have to be prepared by  
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12 manufacturing engineering for any of the subprocesses of production, the effect of the  
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14 various entry points is different. On the extreme side where final products are kept at stock,  
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16 the effect of an order restricts itself to the distribution of the finished product (COEP-1  
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18 equals Ship-to-Stock). The second COEP indicates that shipment processes have to be  
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20 included into the specific activities (Make-to-Stock). When assembly activities belong to  
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22 the execution of an order the COEP positions itself at point 3 (Assemble-to-Order) and in  
23  
24 the case of manufacturing of parts at point 4 (Make-to-Order). Engineering-on-order will  
25  
26 mostly result in purchasing specific parts and materials for that order and enters the  
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28 manufacturing process at point 5 (Buy-to-Order). Downstream of the COEP no stocks  
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30 should be available for sales and that the logistic decisions mostly affect the risks and  
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32 opportunities for accepting orders. Olhager (2003) discusses the pros and cons for shifting  
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34 the Order Entry Point forwards and backwards. Upstream decisions direct themselves at the  
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36 risks coming along with investing in stocks. The COEP represents in most cases the latest  
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38 stock point in the logistic chain; from this point on client's orders have to be delivered.  
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40 Before this entry point, the forecasts of the orders guides the planning of manufacturing  
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42 activities; for example, the production planning might be based on MRP-II (Andries &  
43  
44 Gelders, 1995, p.36; de Haan et al., 2001, p. 107). After this entry point, the emphasis on  
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46 control of manufacturing shifts to lead-time and flexibility since specific customer  
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48 requirements have to be met (the agility of the supply chain).  
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4 Thus, the dilemma for the engineering process remains how to reduce costs by reuse of  
5 designs and at the same time reduce total lead-time while clients have specific  
6 requirements. Similarly, to the material flow, the product information flow has a point  
7 where a custom order enters the process. The product information flow generates the  
8 related specifications and instructions for the manufacturing process. The position of the  
9 Order Specification Entry Point (OSEP) indicates the amount of engineering work before  
10 any order is specified for manufacturing and logistics. The more the design and  
11 configuration has been developed in advance, the less the amount of engineering work that  
12 remains to be done for processing a specific order. When the client accepts an order for an  
13 already defined product, the product information is then ready for manufacturing. In such a  
14 case, the order information is directly transferred to production engineering or shipment  
15 and distribution (OSEP-1 in Figure 2). Position 2 of the OSEP indicates that production  
16 engineering has to transform the standard information from engineering into information  
17 for manufacturing; the order does not require any specific engineering. Either Engineering-  
18 to-Order leads to adaptations of existing configurations (OSEP-3) or a total dedicated  
19 design (OSEP-4). The product architecture has a strong influence on the position of this  
20 point. Any change in requirements from clients that leads to a new design or similar effects,  
21 moves the position of the OSEP to point 4 with its lead-times. The points OSEP-1 and -2  
22 indicate how successful a company is by reusing configurations.

## 2.2 *Product Flexibility and the Order Entry Matrix*

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The choice for a specific OSEP does not necessarily indicate the use of a specific COEP or  
vice versa. The choice of each point depends on rather independent factors. Since we  
distinguish two Order Entry Points, these points might be put together in a matrix (see

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4 Figure 3). Different products and constructions may require different positions of these  
5 points in the Order Entry Matrix. When an OSEP for a certain product architecture allows  
6 acceleration of the order processing during the specification process, management has still  
7 freedom in positioning the COEP.  
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14 [Insert Figure 3 about here]  
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17 The choice of the COEP determines mostly the performance of manufacturing and  
18 logistics. The decision for the COEP one derives from:  
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- 21 • the availability of the product specification for production;
  - 22 • the permitted lead-time;
  - 23 • the frequency of expected sales of individual modules.
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31 The Order Entry Matrix reveals which measures to take for reducing the lead-time and  
32 increasing the productivity and flexibility. Moving the Entry Points downstream will  
33 reduce the lead-times and improve the reuse of product configurations.  
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38 When a company has different OSEP/COEP combinations that might be attributed to three  
39 reasons. Firstly, some product architectures and components require only assembly for a  
40 specific order while at the same time specific materials have to be purchased. Secondly,  
41 special requirements influence only part of the total design; this implies that some parts are  
42 not affected while other products or components need a redesign to meet customer  
43 demands. Finally, the whole range of products of a company can have different  
44 combinations; standard products have a different combination than products with much  
45 engineering work.  
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4 The pull from the market for dedicated variety as a result from customer demands should  
5 be regarded as given. The product flexibility can be illustrated by positioning each variant  
6 within the Order Entry Matrix. Before doing so, the product has to be broken down in  
7 components called modules. This product architecture follows the definition of modules as  
8 presented by Bikker & van der Heyden (1987); Weinbrenner & Ehrlenspiel (1993) have  
9 presented a similar breakdown in modules, sub-assemblies, etc. In Figure 4 we see different  
10 modules as part of the total product family. One will find basic modules in each product;  
11 client specifications do not influence the design of this type of module. Standard modules  
12 refer to modules from which different designs are available and which have to be used in  
13 each product. Examples of such a module might be the choice for a 110V or 230V power  
14 supply. Standard optional modules are features and additions that the client might choose  
15 from a short-list. When the client specification cannot be related to these modules, a special  
16 module might be created.  
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36 [Insert Figure 4 about here]  
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38 When applying the Order Entry Matrix, a product family can be configured consisting of  
39 assemblies and parts. The sales and engineering process should direct client requirements to  
40 standard modules, standard option modules and specials. By minimising the use of special  
41 modules, the dilemma of variants and variety will be met. Such a family of products  
42 configured in modules each serving an original function or sub-function provides one of the  
43 most promising answers to the dilemma. On this matter, Eekels (1993) has already pointed  
44 out that the relationship between client and supplier exists on the exchange of functions.  
45 Similarly, Meyer & Utterback (1993) describe the core capability as keystone for  
46 configuring products and product families. In that view, the underlying value of a product  
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4 family is represented by the core capabilities of products and the value for the customer;  
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6 both the core capability and the value resemble Eekels' description of function.  
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### 10 **3. ENGINEERING AND ORDER ENTRY POINTS**

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12 The implementation in the industry of this matrix shows considerable reductions in lead-  
13 time and costs in the design and manufacturing processes. Companies implementing the  
14 matrix and the modules reduce the impact of client specifications by offering a complete  
15 range of basic, standard and standard optional modules. By configuring the product  
16 structure in such a way that the impact of specials is as low as possible, it also improves the  
17 OSEP/COEP position; that way a proper product structure reduces the lead-times and  
18 improves as well the productivity of the total design and manufacturing process.  
19 Nevertheless, companies will only benefit from the modular design if they implement  
20 changes in the operations of sales, engineering and manufacturing. These changes should  
21 be supported by effective control. This paper offers the opportunity to analyse the effects of  
22 the Order Entry Points on the engineering process, its control and the organisational  
23 implications.  
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#### 42 **3.1 *Impact of Modular Design***

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44 The most effective way of managing the engineering process is by modularisation. This  
45 topic has been widely investigated but weakly linked to the Order Entry Points in that same  
46 literature. The OSEP indicates the type of work and the amount of work to be done for a  
47 customer order. For example, a reduction in engineering efforts will only be possible if the  
48 product design consists of standard modules, basic modules and (sometimes) optional  
49 modules. The foremost effect of the Order Entry Matrix and the belonging modular design  
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4 constitutes the different modus operandi for the engineering process. It creates a  
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6 disconnection between processing customer orders with specific requirements and product  
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8 development aiming a generic architecture covering a wide range of (potential)  
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10 requirements.  
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14 The purpose of the review of the case studies is whether this change has been implemented  
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16 into the organisational structure of engineering. The nature of these two types of  
17  
18 engineering might differ too; the processing of customer orders, incl. special modules, is  
19  
20 characterised by standard working methods, while product development requires a project-  
21  
22 oriented approach. The changes caused by the concepts of the Order Entry Points and  
23  
24 modular design will turn part of the management of the engineering process into operations  
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26 management. Hence, the framework for engineering management, based on the Order Entry  
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28 Point, consists of the standard working methods for the conversion of customer requirement  
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30 into modules for modular product architectures, the management of customer order  
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32 activities and the separate development of new product architecture for future demands.  
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34 The study aims also at disclosing which other issues emerge in engineering management  
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36 for operational control and to what extent integration of sales, engineering, manufacturing  
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38 and logistics occurs.  
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### 45 46 **3.2 Case Studies** 47

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49 Five cases have been examined to understand the impact of the Order Entry Matrix and  
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51 modular product architecture on the management of the engineering processes (see Table  
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53 1), using this framework. Each of these cases represents an in-depth-study of typically 8-9  
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55 months, comprising of both analysis of the specific problems of a company and the  
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57 detailing of the solution. Because of this reason the table lists the original scope of the  
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4 studies. The five case studies represent a variety of companies, each of them typical  
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6 engineering and manufacturing companies that produce on order (before the  
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8 implementation of the Order Entry Matrix). The issues for the engineering processes and  
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10 management have been listed in the last column of Table 1.  
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14 [Insert Table 1 about here]  
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17 The first four cases concerned both the engineering process and the manufacturing process;  
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19 the integrated improvement of the primary process to meet shifting performance  
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21 requirements stood at the heart of these studies. These four cases constitute industrial  
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23 companies that produce small-series to medium-sized series of equipment for industrial use,  
24  
25 mostly. Traditionally, engineering activities during the conversion from customer  
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27 requirements to manufacturing instructions resulted in lengthy lead-times, reduced  
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29 efficiency and difficult operational control. Although the specific solutions for the  
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31 companies varied, they all embodied the introduction of Order Entry Points and modular  
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33 design. The studies have resulted in improvement of the conflicting requirements of lead-  
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35 time, product flexibility and productivity.  
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41 The fifth case study did focus on the engineering process. The company executed orders for  
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43 the construction industry, mainly by producing equipment for plants. The company's  
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45 competitive advantage was to deliver custom-made equipment, in contrast to the  
46  
47 competitors that delivered modular designs. Additionally, the analysis of five projects  
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49 revealed that the losses amounted up to 20% per project due to an excess of engineering  
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51 hours. This excess could be avoided by a more standardised operating procedure for the  
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53 design and engineering of the products (based on small increments, that way approaching  
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55 tailored design), in a way moving towards OSEP-1. A computer program based on a  
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4 standardised design and modular components has been developed to conduct the pre-design  
5 and initial stages of the engineering process. The proposal decreased the number of hours  
6 and decreased the lead-time. Because of the low number of projects and specific  
7 requirements it is not possible to assess the exact improvements; an estimate showed that  
8 the payback time, for the standardised design and the implementation, could be 1-1½ years.  
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17 Additionally, the shift in the Order Entry Points implies a separation between the  
18 processing of customer orders and product development. Only in Case B this has not been  
19 implemented due to the nature of the products, and due to the assessment of the company  
20 that their basic design would not need any upgrades for a while. In the old situations the  
21 engineering of customer orders and product development were intertwined in the skills and  
22 capabilities of individual engineers. The working methods introduced by modular design  
23 entail the division of the engineering process in three separate processes: (a) the  
24 engineering of special modules, (b) the preparation of documentation for manufacturing in  
25 case of OSEP-3 and OSEP-2, and (c) the development of new product designs. Yet, the  
26 strict separation of these processes (and their control) has not been implemented in any of  
27 the engineering departments; neither were engineers purely allocated to products or product  
28 families.  
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46 Furthermore, the process for managing market demands becomes paramount. A modular  
47 product architecture improves the response to specific customer demands at the expense of  
48 product flexibility. Developing each product on its own offers the best flexibility to the  
49 market; however, it does not solve the problems related to productivity and lead-time. The  
50 architecture of the product limits the implementation of any customer requirement; hence,  
51 in a certain way the product architecture decreases the product flexibility. Then it becomes  
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4 more important to incorporate a well-defined set of requirements into the basic design.  
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6 Requirements outside the scope of the requirements should be treated as specials; processes  
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8 should be in place to avoid overdraft on these types of projects (e.g. easier to sell for sales  
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10 representatives but more costly to make). Although recognised as key point of strategy,  
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12 none of the companies, except A, did actively control the tuning between sales and  
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14 engineering on this point.  
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19 That brings us to the issues of integration between sales, engineering, manufacturing and  
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21 logistics. Since these companies produce small series to medium-sized series and often  
22  
23 incorporate engineering efforts in orders, the implementation of the Order Entry Points  
24  
25 covers mostly the logistic issues. That leaves the amalgamation of sales, engineering and  
26  
27 manufacturing as remaining issue. From Table 1 it appears that only in one case a product  
28  
29 configuration system has been developed for assisting sales representatives while in the  
30  
31 other cases the integration focuses more on standard procedures. Case C has also the largest  
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33 series produced per year, may be the reason why such becomes feasible. In the other four  
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35 cases, the companies do not see any need to go beyond the standardised working methods.  
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### 40 41 **3.3 Discussion of Findings**

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43 At two companies, the engineering department resisted to the change the Order Entry  
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45 Points would bring along. In Case A, the implementation was delayed until the engineering  
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47 manager left the company. In Case E, the project managers, which are engineers  
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49 themselves, did initially not acknowledge the advantages of modular design; only when it  
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51 became clear that the excess of project budgets was related to an excess of engineering  
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53 efforts, the modular design and the standard working method were favoured. The different  
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55 modes of working for modular product architecture contradicts with the skills of engineers  
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4 to find specific solutions, which causes the engineers (or department heads) to object to  
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6 change.  
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10 This resistance comes along with the disconnection of operations (processing customer  
11 orders within the bandwidth of the modular design) and product development in  
12 engineering. One group should concentrate on the processing of orders and one on product  
13 development. The implementation of this working method did not properly take place in  
14 any of the companies, although Gulati & Eppinger (1996) indicate the close relationship  
15 between product configuration and organisational structure. The relative size of the  
16 engineering departments in the companies investigated and the specific knowledge of  
17 engineers make it more difficult to approach engineering management similarly as  
18 operations management.  
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31 In addition, the management of customers' requirements calls for an early detection of  
32 shifts and trends. Shifting trends and demands should lead to decision-making on optional  
33 modules, basic modules, conversion from special modules to optional modules and  
34 redesign of the product architecture (upgrade or new design). A loop to do so would  
35 suffice; this would act as a feedforward before the order processing to avoid an inflow of  
36 too many orders as custom design. Additionally, it would be necessary to include a  
37 detection of trends in customer orders to anticipate on future demands. This detection of  
38 shifts and the active management of the engineering process would also require the design  
39 of subsequent product families and platforms. Accumulation of customer demands and  
40 feedback from the routine engineering process and the manufacturing process might result  
41 in the need for developing new product families or platforms. Especially, the low level of  
42 cooperation between sales, engineering and manufacturing on this point can be seen as an  
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4 inherent weakness of all companies investigated. Engineering management does not  
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7 become a management of engineering unless it integrates with sales, production, etc. to  
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10 meet overall performance requirements.

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12 Furthermore, in conjunction with the previous paragraph, a modular product design offers  
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14 also possibilities for modular innovation, one of the four types of innovation that  
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16 Henderson & Clark (1990) distinguish. The concept of architectural innovation offers the  
17  
18 possibility to revolutionise product design and the possibility to look for other applications,  
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20 e.g. in other product-market combinations. To manage this process, the Model for the  
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22 Innovation Impact Point (Dekkers, 2005, pp. 306-308) is proposed to link the accumulation  
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24 of incremental changes, component innovation and architectural innovation to the strategy  
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26 for product market combinations. However, the architecture of a modular design will  
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28 inhibit architectural innovation (see Henderson & Clark [1990]). Ultimately, an active  
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30 management of the engineering process combined with this model will increase the  
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32 innovative capability of engineering and manufacturing companies.  
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#### 39 **4 CONCLUSIONS**

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41 The review of five cases on the application of the Order Entry Matrix and modular design  
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43 demonstrates the strong intertwining between the product architecture and the operational  
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45 control for both the manufacturing and the engineering processes. Traditionally not well  
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47 researched, the case studies show that the application of the Order Entry Matrix to meet  
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49 performance requirements (lead-time, product flexibility and productivity) has a strong  
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51 impact on the engineering processes. The characteristics of engineering allow a limited  
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53 range of interventions, esp. more difficult task allocation to engineers, putting more stress  
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55 on adequate capacity management. Also, the “freedom” of engineers seems at stake. The  
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management of the engineering process turns out to be weakly developed in industry and resistance to change persists in the implementation of more adequate operational control.

The framework for operations management of engineering, introduced in this paper, encompasses the recognition of Order Entry Points in the engineering processes, the standard working methods for the conversion of customer requirements into modules of a modular product architecture, the management of customer order activities and the separate development of new product architecture for future demands. Alternatively, a modular design increases the innovative capability of firms through architectural innovation. The base for integrated operations management of engineering, embedded within the total business processes, requires elaboration, mostly by connecting different strands of research.

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Table 1: Overview of case studies. The second columns indicates the types of products that the companies produce and next to it the main performance criteria for the studies. The fourth column reflects the impact of the in-depth study on the Order Entry Points. The two columns on the right list which engineering management and integration issues were encountered during the studies.

Case	Products	Scope of Study	Order Entry Points	Engineering Issues	Integration Issues
A	Equipment food industry (large custom-made equipment 10/yr)	Reduction overall lead-time (from 9 months to 6 months), wide variety of customer demands	Start of project: OSEP-4/COEP-5. After redesign: Basic/standard OSEP-3/COEP-5 (17/6 functions), Specials OSEP-4/COEP-5.	Draft assembly plan as standard documentation. Product architecture required extensive redesign. Resistance to change: manager of Engineering Department maintaining the status quo, introduced 7 years later.	Draft assembly plan
B	Rotary screen printing machines (textile printing) (250/yr)	Productivity, lead-time (from 6 to 2 weeks), flexibility	Start of project: OSEP-4/COEP-5. After redesign: OSEP-2/COEP-3/4/5	Redesign of product architecture necessary to facilitate new manufacturing organisation. Reduction of engineering efforts per order	Product configuration (standardised)
C	Display counters for retail (food) (500/yr)	Reduction overall lead-time (from 8 to 4 weeks), engineering effort not in balance with market prices	Start of project: 80% OSEP-4, 20% OSEP-3, COEP-4/5. After redesign: 80% OSEP-3, COEP-3/4.	Redesign of product architecture. Reduction of engineering lead-time from 3.5 weeks to 1.5 weeks: integration with sales.	Product configurator
D	Packaging machines (50/yr)	Reduction overall lead-time (from 12 to 8 weeks), flexibility for customer demands	Start of project: OSEP-4/COEP-3/4/5. After implementation: Basic/standard OSEP-3/COEP-3/4/5, Specials OSEP-4/COEP-4/5	Minor redesign of product architecture. Loop for detecting shifting market demands and decision-making.	Draft assembly plan
E	Plant automisation construction industry (5/yr)		Start of project: OSEP-4/COEP-5. After implementation: OSEP-3/COEP-5	Modular and incremental pre-design to meet a wide variety of customer demands	Standard engineering (software). Standard production method

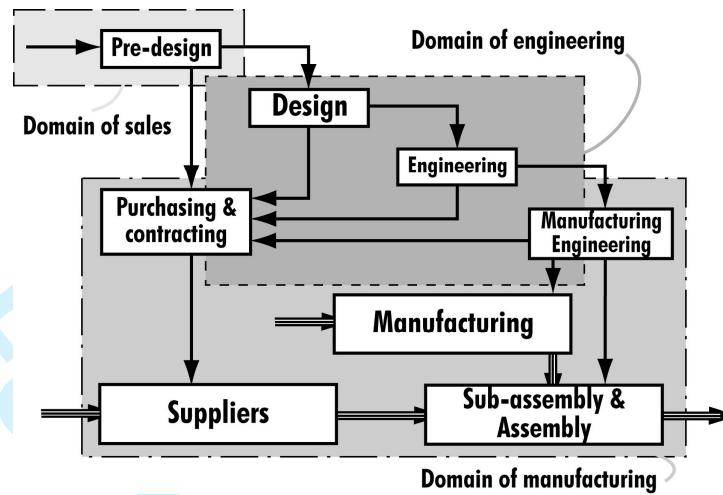


Figure 1: Simplified, generic total primary process. The total primary process consists of two flows: (1) the material and logistic flow in the domain of manufacturing and (2) the information flow, product and process data, related to product development and engineering.

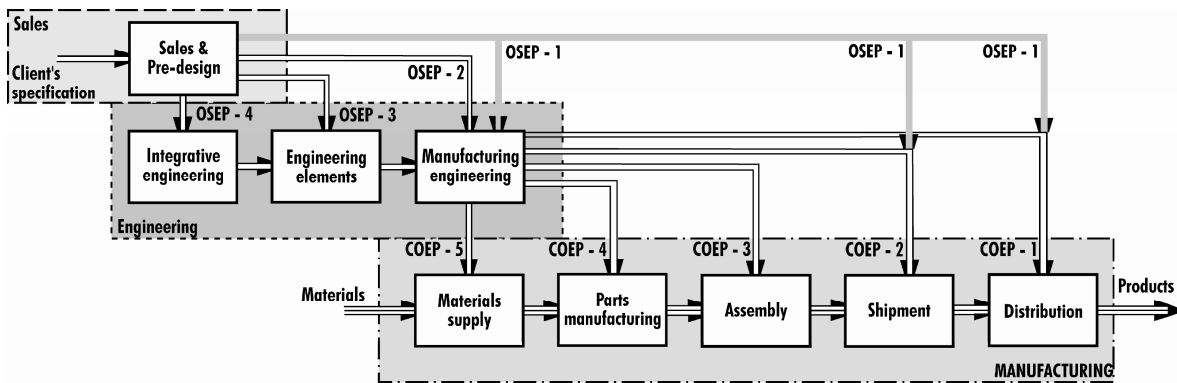


Figure 2: Position of the Order Entry Points in the primary process of design, engineering, manufacturing and logistics. To simplify the figure points of stock have been omitted. OSEP-1 (Order Specification Entry Point) indicates that customer requirements are directly transferred into production instructions, while OSEP-4 points to Engineering-to-Order. Similarly in the material flow: COEP-1 (Customer Order Entry Point) tells that orders are delivered directly from stock, while COEP-5 marks Make-to-Order.

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Figure 3: Order Entry Matrix. The position in this matrix indicates the efforts required to fulfil an order. Products might consist of different components with different combinations of the Order Entry Points.



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Functions Variants	Basic	Standard	Option	Client requirements
One	Basic module			Special module
Limited		Standard module		
Mostly one			Optional module	

Figure 4: Grid for modular product architecture. The basic module is always part of a product. Standard modules are also needed but the configurations vary based on customer requirements. Specific customer requirements result in either pre-designed optional modules or special modules (designed per order).

## Engineering Management and the Order Entry Point

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**ABSTRACT**

Traditionally, most literature has focused on the impact of Order Entry Points on manufacturing and logistics. Current literature about these entry points undervalues the effects on the engineering process and the writings on modular design hardly discuss the relationship with operations management. To assess and review the consequences for engineering management, a framework has been developed based on earlier research, covering the standard working methods for the conversion of customer requirements into components of a modular product architecture, the management of customer order activities and the separate development of new product architectures for future demands.

Five case studies served as base for the investigation of engineering management. Although it might be expected that operations management for the engineering process should not differ from that of manufacturing, the case studies prove otherwise. The characteristics of engineering activities allow a more limited range of interventions, putting more stress on adequate capacity management. Additionally, the implementation of modular design does create sometimes resistance to change. Strategically, modular design has the advantage of architectural innovation. However, the implementation of the Order Entry Matrix in engineering management shows that control of engineering activities is weakly developed in industry.

**Keywords:** Order Entry Points, modular design, engineering management, customisation, architectural innovation

**Word count:** 6672

6106 (excluding title page and text figures, tables)

## 1 INTRODUCTION

With the industrial focus shifting to a lapse in productivity, while decreasing the integral lead-times and offering a larger variety of products, the drive for integral approaches toward operational management increases. Many companies still struggle to meet these often-conflicting requirements (the trade-off is discussed by Andries & Gelders [1995, p. 31]) and find themselves confronted with the question how to organise their processes. The fulfilment of customer demands often ends in longer lead-times and higher costs to design and manufacture dedicated products caused by the impact of the specific requirements on the total configuration of products. Alternatively, a tendency of standardising products will hand over orders and clients to the competition, due to its inherent cost and inflexibility. Companies have no choice but to meet simultaneously the requirements for product flexibility, lead-time and productivity. Especially, since the future demands on the performance of an organisation will result into further integration of sales, engineering and manufacturing, according to Furukawa (1993).

A workshop in June 2004, organised by the Dutch Ministry of Economic Affairs and attended by both practitioners and academics, highlighted the continuing industrial need for integral approaches towards design, engineering, manufacturing and logistics to meet the changing requirements of contemporary markets. Management research has already generated integral approaches to cope with the conflicting requirements of productivity, lead-time and variety; especially, the concepts for the Order Entry Points and modular design address these industrial challenges. The Order Entry Point is also known as the Customer Order Decoupling Point (by most authors), while some call it the Order Penetration Point (Sharman, 1984) and Sabri & Beamon (2000) label it the Product

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7 Configuration Point; Order Entry Point seems a more appropriate term in this respect.  
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10 According to these approaches, management should consider the decisions for positioning  
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12 the Order Entry Points to meet performance requirements adequately, often in combination  
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14 with modular design.  
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### 16 17 **1.1 Background** 18

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20 Most literature pays attention to the impact of the Order Entry Points (and the related  
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22 modular design) on logistics and operations. Originally, Sharman (1984) introduced the  
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24 Order Entry Points for logistic control and Wemmerlöv (1984) pointed to the existence of  
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26 different modes of operation for Make-to-Stock, Make-to-Order and Assemble-to-Order.  
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28 These writings were quickly followed by others, like Hoekstra & Romme (1985), explicitly  
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30 introducing the Order Entry Points to improve logistic management in industrial  
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32 companies. Meanwhile, it has been developed to address logistic management (e.g.  
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34 Christopher & Towill, 2000; van Donk, 2001; de Haan et al., 2001; Vries et al., 1999;  
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36 Wanke & Zinn, 2004), Supply Chain Management (like Croxton et al., 2001; Graves &  
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38 Willems, 2000, Lee & Lau, 1999; Mason-Jones et al., 2000; Sabri & Beamon, 2000), IT  
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40 applications (for example, Andries & Gelders, 1995, p. 36; Giesberts & van de Tang, 1992;  
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42 Sabri & Beamon, 2000), and outsourcing (e.g. van der Vlist et al., 1997). A stream of  
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44 literature sees Order Entry Points as concept for connecting the lean paradigm with the  
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46 agility of the supply chain (Christopher, 2000; Naylor et al., 1999). Others, like Mason-  
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48 Jones et al. (2000) and Schuh et al. (1998), emphasise the strategic flexibility of modular  
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50 designs connected to the Order Entry Points; this flexibility has also been a cornerstone for  
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52 literature on product families and platforms (like Meyer & Utterback, 1993). Generally  
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7 speaking, much emphasis is given to consequences for order processing, stock control,  
8 stock replenishment and performance improvement.  
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12 But what about the modular design and its link to engineering management? Within the  
13 strand of literature on logistics and Supply Chain Management, the modular design is  
14 mostly taken either as starting point or as consequence of the Order Entry Points (e.g.  
15 Mikkola & Skjøtt-Larsen, 2004). While at the same time, most literature on modular design  
16 (e.g. Sanchez, 2004; Simpson et al., 2001; Stone et al., 2000) does not include  
17 manufacturing strategy or logistics as driver for the configuration of products. Riedel &  
18 Pawar (1998) highlight that the concepts of design and manufacturing are not linked in  
19 literature and that the interaction of product design and manufacturing strategy is under-  
20 researched. Spring & Dalrymple (2000) come to the same conclusion when examining two  
21 cases of product customisation: manufacturing issues get little attention during design and  
22 engineering. The initial case study resulting from Action Research into Strategic Capacity  
23 Management (Dekkers, 2003) demonstrates this notion as well. For the Order Entry Points,  
24 Rudberg & Wikner (2004) distinguish the engineering and production dimension in their  
25 conceptual paper, while earlier work by Bikker & Dekkers (1994) elaborates on the  
26 consequences for engineering. Consequently, most literature has ignored the vital link  
27 between engineering processes and manufacturing strategy and hardly discusses the impact  
28 on operations management of engineering.  
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## 51 **1.2 Research Methodology**

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53 In this context, five manufacturing companies have been examined on the impact of Order  
54 Entry Points; the scope did include manufacturing management and engineering  
55 management (product development in these companies has been embedded in the  
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7 engineering department). The theory of modular design leading to a coherent approach to  
8 product architectures originates from earlier research (Bikker, 1992; van der Sterre, 1992).  
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10 Logistic implications and a proposal for control have been discussed in Dekkers & Sopers  
11 (2001). The earlier research shows the successful implementation of the concept though it  
12 implies that companies have to adapt their operation's practices and systems. Action  
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14 Research in all five case studies – with the findings in separate reports - revealed that a new  
15 organisational structure with upstream Order Entry Points would prove beneficial.  
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19 However, it remained unclear which impact these Order Entry Points would have on  
20 control of engineering to meet customer demands and therefore this has been examined  
21 separately (this was one of the remaining research topics mentioned by Bikker & Dekkers  
22 [1994]). Nonetheless, engineering management cannot be separated from the  
23 implementation in manufacturing and logistics. Hence, the issues for engineering  
24 management have been extracted from the reports of the five case studies. Since each case  
25 study contains unique solutions, the research reported here focuses on commonalities with  
26 respect to issues in engineering management; additionally, the subject of integration of  
27 sales, engineering, manufacturing and logistics has been reviewed.  
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### 45 **1.3 Scope of Paper**

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48 Consequently, this paper will address the link between engineering (including product  
49 development) and manufacturing strategy and it will discuss the impact of the Order Entry  
50 Points on the operations of engineering. This way it will connect modular design as an  
51 engineering concept to the Order Entry Points. The publication will also provide a  
52 framework for engineering management based on the Order Entry Points. Furthermore, it  
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7 will analyse the issues related to the implementation in engineering management. The  
8 added value is the disclosure of a field not well-studied in literature.  
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12 The paper will start with a description of the processes within industrial companies,  
13 directed at the engineering and manufacturing processes. Section 2 links these processes to  
14 the Order Entry Points mainly based on the previous publications, which relate closely to  
15 other literature in this field; however, the benefit is the distinction of Order Entry Points for  
16 both production and engineering processes. For some readers these theories might prove  
17 common ground. Section 3 introduces the theoretical framework for engineering  
18 management by the link to the Order Entry Points. This section presents the five case  
19 studies conducted within this framework and reports on the findings of the research into  
20 engineering management. Section 4 concludes the paper and displays the recommendations  
21 following from this research, which enables companies to cope with the contemporary  
22 challenges for performance and strategy more effectively caused by the trends of increasing  
23 variety and customisation.  
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## 41 **2. ORDER ENTRY POINTS**

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43 That the current trend of customisation affects the control of operations within industrial  
44 companies leaves no doubt. Lampel & Mintzberg (1996) demonstrate the change of the  
45 demand by clients and the penetration of this demand into the organisation. Child et al.  
46 (1991) note that in some cases, companies attribute as much as 30% of their costs to  
47 product variety, while these variations account for as little as 3% of sales. Wüpping (1998)  
48 notes that especially during difficult times companies tend to accept any customer  
49 requirement not to leave any space to competitors. This illustrates the impact of the  
50 strategic choice on the performance of companies with the continuum of strategic choice  
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7 ranging from pure standardisation to pure customisation. Pure standardisation leaves no  
8 room for differentiation, segmented standardisation may provide different distribution  
9 services or channels to different customer segments, customised standardisation  
10 encompasses final assembly of modules according to specific customer requirements,  
11 tailored customisation includes customer-specific components and modules in the final  
12 assembly, and pure customisation covers all specific process to meet unique customer  
13 requirements. According to Lampel & Mintzberg (1996) these five types, especially the  
14 trend for standardised customisation, effects the way anyone looks at organisations and the  
15 control of the primary process.  
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31 Figure 1 describes the design processes, engineering processes and manufacturing  
32 processes; it distinguishes two main processes: the product information flow and the  
33 material flow. During the product information flow, client requirements transform into  
34 specifications and instructions for manufacturing. The material flow concerns the  
35 manufacturing of parts and the assembly of the final products from parts and purchased  
36 parts. The *Sales Process* of this model translates the client's requirements into  
37 specifications for engineering. The sales process is not only performed by the sales force  
38 but might involve other personnel, such as sales engineers, project engineers, engineers and  
39 technical buyers from the customer. The *Engineering Process* transforms the specifications  
40 from the sales process into standards and information for production, i.e., drawings,  
41 assembly instructions, etc. Before using these standards and information, the manufacturing  
42 engineering function adds production instructions for the actual production process. The  
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8 *Manufacturing Process*, including purchasing materials and parts, converts these materials  
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10 and parts into products ready for distribution and delivery.

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12 When the delivery times for a company decrease, the turnaround for logistic control arrives  
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14 if the lead-time for delivery of specific orders approaches or becomes shorter than the  
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16 throughput time for engineering and manufacturing. Especially in the case that clients  
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18 require specials or specific requirements they have a few options for the product  
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20 information flow and the material flow. For the product information flow, companies might  
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22 reduce further on lead-time through:  
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- 25 • introducing new methods of working;
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- 27 • concurrent and simultaneous engineering;
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- 30 • reuse of constructions.
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35 The introduction of new methods, concurrent and simultaneous engineering will not always  
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37 have the desired effect. The options will reduce delivery time but they approach the specific  
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39 client requirements from a project-oriented point of view (Dekkers, 1997). The reuse of  
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41 constructions makes it possible to apply already developed components and assemblies for  
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43 a new client order.  
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## 46 **2.1 Order Entry Points**

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56 Within the material flow companies have only as an option to manufacture on stock,  
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58 located on an appropriate point within the manufacturing process. This point of stock is  
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8 called the Custom Order Entry Point. The point where an order enters the material flow, the  
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10 Custom Order Entry Point (COEP), determines which specific activities have to be  
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12 undertaken after the start of a custom order (Figure 2); please note that the points of stock  
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14 have been omitted from the figure. Although instructions have to be prepared by  
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16 manufacturing engineering for any of the subprocesses of production, the effect of the  
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18 various entry points is different. On the extreme side where final products are kept at stock,  
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20 the effect of an order restricts itself to the distribution of the finished product (COEP-1  
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22 equals Ship-to-Stock). The second COEP indicates that shipment processes have to be  
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24 included into the specific activities (Make-to-Stock). When assembly activities belong to  
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26 the execution of an order the COEP positions itself at point 3 (Assemble-to-Order) and in  
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28 the case of manufacturing of parts at point 4 (Make-to-Order). Engineering-on-order will  
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30 mostly result in purchasing specific parts and materials for that order and enters the  
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32 manufacturing process at point 5 (Buy-to-Order). Downstream of the COEP no stocks  
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34 should be available for sales and that the logistic decisions mostly affect the risks and  
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36 opportunities for accepting orders. Olhager (2003) discusses the pros and cons for shifting  
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38 the Order Entry Point forwards and backwards. Upstream decisions direct themselves at the  
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40 risks coming along with investing in stocks. The COEP represents in most cases the latest  
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42 stock point in the logistic chain; from this point on client's orders have to be delivered.  
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44 Before this entry point, the forecasts of the orders guides the planning of manufacturing  
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46 activities; for example, the production planning might be based on MRP-II (Andries &  
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48 Gelders, 1995, p.36; de Haan et al., 2001, p. 107). After this entry point, the emphasis on  
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50 control of manufacturing shifts to lead-time and flexibility since specific customer  
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52 requirements have to be met (the agility of the supply chain).  
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7 Thus, the dilemma for the engineering process remains how to reduce costs by reuse of  
8 designs and at the same time reduce total lead-time while clients have specific  
9 requirements. Similarly, to the material flow, the product information flow has a point  
10 where a custom order enters the process. The product information flow generates the  
11 related specifications and instructions for the manufacturing process. The position of the  
12 Order Specification Entry Point (OSEP) indicates the amount of engineering work before  
13 any order is specified for manufacturing and logistics. The more the design and  
14 configuration has been developed in advance, the less the amount of engineering work that  
15 remains to be done for processing a specific order. When the client accepts an order for an  
16 already defined product, the product information is then ready for manufacturing. In such a  
17 case, the order information is directly transferred to production engineering or shipment  
18 and distribution (OSEP-1 in Figure 2). Position 2 of the OSEP indicates that production  
19 engineering has to transform the standard information from engineering into information  
20 for manufacturing; the order does not require any specific engineering. Either Engineering-  
21 to-Order leads to adaptations of existing configurations (OSEP-3) or a total dedicated  
22 design (OSEP-4). The product architecture has a strong influence on the position of this  
23 point. Any change in requirements from clients that leads to a new design or similar effects,  
24 moves the position of the OSEP to point 4 with its lead-times. The points OSEP-1 and -2  
25 indicate how successful a company is by reusing configurations.

## 2.2 *Product Flexibility and the Order Entry Matrix*

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The choice for a specific OSEP does not necessarily indicate the use of a specific COEP or vice versa. The choice of each point depends on rather independent factors. Since we distinguish two Order Entry Points, these points might be put together in a matrix (see

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8 Figure 3). Different products and constructions may require different positions of these  
9 points in the Order Entry Matrix. When an OSEP for a certain product architecture allows  
10 acceleration of the order processing during the specification process, management has still  
11 freedom in positioning the COEP.  
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17 [Insert Figure 3 about here]  
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20 The choice of the COEP determines mostly the performance of manufacturing and  
21 logistics. The decision for the COEP one derives from:  
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25 • the availability of the product specification for production;  
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27 • the permitted lead-time;  
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29 • the frequency of expected sales of individual modules.  
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33 The Order Entry Matrix reveals which measures to take for reducing the lead-time and  
34 increasing the productivity and flexibility. Moving the entry points downstream will reduce  
35 the lead-times and improve the reuse of product configurations.  
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40 When a company has different OSEP/COEP combinations that might be attributed to three  
41 reasons. Firstly, some product architectures and components require only assembly for a  
42 specific order while at the same time specific materials have to be purchased. Secondly,  
43 special requirements influence only part of the total design; this implies that some parts are  
44 not affected while other products or components need a redesign to meet customer  
45 demands. Finally, the whole range of products of a company can have different  
46 combinations; standard products have a different combination than products with much  
47 engineering work.  
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7 The pull from the market for dedicated variety as a result from customer demands should  
8 be regarded as given. The product flexibility can be illustrated by positioning each variant  
9 within the Order Entry Matrix. Before doing so, the product has to be broken down in  
10 components called modules. This product architecture follows the definition of modules as  
11 presented by Bikker & van der Heyden (1987). Weinbrenner & Ehrlenspiel (1993) have  
12 presented a similar breakdown in modules, sub-assemblies, etc. In Figure 4 we see different  
13 modules as part of the total product family. One will find basic modules in each product;  
14 client specifications do not influence the design of this type of module. Standard modules  
15 refer to modules from which different designs are available and which have to be used in  
16 each product. Examples of such a module might be the choice for a 110V or 230V power  
17 supply. Standard optional modules are features and additions that the client might choose  
18 from a short-list. When the client specification cannot be related to these modules, a special  
19 module might be created.  
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40 When applying the Order Entry Matrix, a product family can be configured consisting of  
41 assemblies and parts. The sales and engineering process should direct client requirements to  
42 standard modules, standard option modules and specials. By minimising the use of special  
43 modules, the dilemma of variants and variety will be met. Such a family of products  
44 configured in modules each serving an original function or sub-function provides one of the  
45 most promising answers to the dilemma. On this matter, Eekels (1993) has already pointed  
46 out that the relationship between client and supplier exists on the exchange of functions.  
47 Similarly, Meyer & Utterback (1993) describe the core capability as keystone for  
48 configuring products and product families. In that view, the underlying value of a product  
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7 family is represented by the core capabilities of products and the value for the customer;  
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9 both the core capability and the value resemble Eekels' description of function.  
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### 12 13 **3. ENGINEERING AND ORDER ENTRY POINTS**

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15 The implementation in the industry of this matrix shows considerable reductions in lead-  
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17 time and costs in the design and manufacturing processes. Companies implementing the  
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19 matrix and the modules reduce the impact of client specifications by offering a complete  
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21 range of basic, standard and standard optional modules. By configuring the product  
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23 structure in such a way that the impact of specials is as low as possible, it also improves the  
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25 OSEP/COEP position; that way a proper product structure reduces the lead-times and  
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27 improves as well the productivity of the total design and manufacturing process.  
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29 Nevertheless, companies will only benefit from the modular design if they implement  
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31 changes in the operations of sales, engineering and manufacturing. These changes should  
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33 be supported by effective control. This paper offers the opportunity to analyse the effects of  
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35 the Order Entry Points on the engineering process, its control and the organisational  
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37 implications.  
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#### 43 44 **3.1 *Impact of Modular Design***

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46 The most effective way of managing the engineering process is by modularisation. This  
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48 topic has been widely investigated but weakly linked to the Order Entry Points in that same  
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50 literature. The OSEP indicates the type of work and the amount of work to be done for a  
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52 customer order. For example, will only be possible if the product design consists of  
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54 standard modules, basic modules and (sometimes) optional modules. The foremost effect of  
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56 the Order Entry Matrix and the belonging modular design constitutes the different modus  
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operandi for the engineering process. It creates a disconnection between processing customer orders with specific requirements and product development aiming a generic architecture covering a wide range of (potential) requirements.

The purpose of the review of the case studies is whether this change has been implemented into the organisational structure of engineering. The nature of these two types of engineering might differ too; the processing of customer orders, incl. special modules, is characterised by standard working methods, while product development requires a project-oriented approach. The changes caused by the concepts of the Order Entry Points and modular design will turn part of the management of the engineering process into operations management. Hence, the framework for engineering management, based on the Order Entry Point, consists of the standard working methods for the conversion of customer requirement into modules for modular product architectures, the management of customer order activities and the separate development of new product architecture for future demands. The study aims also at disclosing which other issues emerge in engineering management for operational control and to what extent integration of sales, engineering, manufacturing and logistics occurs.

### 3.2 *Case Studies*

Five cases have been examined to understand the impact of the Order Entry Matrix and modular product architecture on the management of the engineering processes (see Table 1), using this framework. Each of these cases represents an in-depth-study of typically 8-9 months, comprising of both analysis of the specific problems of a company and the detailing of the solution. Because of this reason the table lists the original scope of the studies. The five case studies represent a variety of companies, each of them typical



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7 engineering and manufacturing companies that produce on order (before the  
8 implementation of the Order Entry Matrix). The issues for the engineering processes and  
9 management have been listed in the last column of Table 1.  
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15 [Insert Table 1 about here]  
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18 The first four cases concerned both the engineering process and the manufacturing process;  
19 the integrated improvement of the primary process to meet shifting performance  
20 requirements stood at the heart of these studies. These four cases constitute industrial  
21 companies that produce small-series to medium-sized series of equipment for industrial use,  
22 mostly. Traditionally, engineering activities during the conversion from customer  
23 requirements to manufacturing instructions resulted in lengthy lead-times, reduced  
24 efficiency and difficult operational control. Although the specific solutions for the  
25 companies varied, they all embodied the introduction of Order Entry Points and modular  
26 design. The studies have resulted in improvement of the conflicting requirements of lead-  
27 time, product flexibility and productivity.  
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41 The fifth case study did focus on the engineering process. The company executed orders for  
42 the construction industry, mainly by producing equipment for plants. The company's  
43 competitive advantage was to deliver custom-made equipment, in contrast to the  
44 competitors that delivered modular designs. Additionally, the analysis of five projects  
45 revealed that the losses amounted up to 20% per project due to an excess of engineering  
46 hours. This excess could be avoided by a more standardised operating procedure for the  
47 design and engineering of the products (based on small increments, that way approaching  
48 tailored design), in a way moving towards OSEP-1. A computer program based on a  
49 standardised design and modular components has been developed to conduct the pre-design  
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7 and initial stages of the engineering process. The proposal decreased the number of hours  
8 and decreased the lead-time. Because of the low number of projects and specific  
9 requirements it is not possible to assess the exact improvements; an estimate showed that  
10 the payback time, for the standardised design and the implementation, could be 1-1.5 years.  
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16 Additionally, the shift in the Order Entry Points implies a separation between the  
17 processing of customer orders and product development. Only in Case B this has not been  
18 implemented due to the nature of the products, and due to the assessment of the company  
19 that their basic design would not need any upgrades for a while. In the old situations the  
20 engineering of customer orders and product development were intertwined in the skills and  
21 capabilities of individual engineers. The working methods introduced by modular design  
22 entail the division of the engineering process in three separate processes: (a) the  
23 engineering of special modules, (b) the preparation of documentation for manufacturing in  
24 case of OSEP-3 and OSEP-2, and (c) the development of new product designs. Yet, the  
25 strict separation of these processes (and their control) has not been implemented in any of  
26 the engineering departments; neither were engineers purely allocated to products or product  
27 families.  
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45 Furthermore, the process for managing market demands becomes paramount. A modular  
46 product architecture improves the response to specific customer demands at the expense of  
47 product flexibility. Developing each product on its own offers the best flexibility to the  
48 market; however, it does not solve the problems related to productivity and lead-time. The  
49 architecture of the product limits the implementation of any customer requirement; hence,  
50 in a certain way the product architecture decreases the product flexibility. Then it becomes  
51 more important to incorporate a well-defined set of requirements into the basic design.  
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7 Requirements outside the scope of the requirements should be treated as specials; processes  
8 should be in place to avoid overdraft on these types of projects (e.g. easier to sell for sales  
9 representatives but more costly to make). Although recognised as key point of strategy,  
10 none of the companies, except A, did actively control the tuning between sales and  
11 engineering on this point.  
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18 That brings us to the issues of integration between sales, engineering, manufacturing and  
19 logistics. Since these companies produce small series to medium-sized series and often  
20 incorporate engineering efforts in orders, the implementation of the Order Entry Points  
21 covers mostly the logistic issues. That leaves the amalgamation of sales, engineering and  
22 manufacturing as remaining issue. From Table 1 it appears that in only one case a product  
23 configuration system has been developed for assisting sales representatives while in the  
24 other cases the integration focuses more on standard procedures. Case C has also the largest  
25 series produced per year, may be the reason why such becomes feasible. In the other four  
26 cases, the companies do not see any need to go beyond the standardised working methods.  
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### 41 **3.3 Discussion of Findings**

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43 At two companies, the engineering department resisted to the change the Order Entry  
44 Points would bring along. In Case A, the implementation was delayed until the engineering  
45 manager left the company. In Case E, the project managers, which are engineers  
46 themselves, did initially not acknowledge the advantages of modular design; only when it  
47 became clear that the excess of project budgets was related to an excess of engineering  
48 efforts, the modular design and the standard working method was favoured. The different  
49 modes of working for modular product architecture contradicts with the skills of engineers  
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8 to find specific solutions, which causes the engineers (or department heads) to object to  
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10 change.

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12 This resistance comes along with the disconnection of operations (processing customer  
13 orders within the bandwidth of the modular design) and product development in  
14 engineering. One group should concentrate on the processing of orders and one on product  
15 development. The implementation of this working method did not properly take place in  
16 any of the companies, although Gulati & Eppinger (1996) indicate the close relationship  
17 between product configuration and organisational structure. The relative size of the  
18 engineering departments in the companies investigated and the specific knowledge of  
19 engineers make it more difficult to approach engineering management similarly as  
20 operations management.  
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33 In addition, the management of customers' requirements calls for an early detection of  
34 shifts and trends. Shifting trends and demands should lead to decision-making on optional  
35 modules, basic modules, conversion from special modules to optional modules and  
36 redesign of the product architecture (upgrade or new design). A loop to do so would  
37 suffice; this would act as a feedforward before the order processing to avoid an inflow of  
38 too many orders as custom design. Additionally, it would be necessary to include a  
39 detection of trends in customer orders to anticipate on future demands. This detection of  
40 shifts and the active management of the engineering process would also require the design  
41 of subsequent product families and platforms. Accumulation of customer demands and  
42 feedback from the routine engineering process and the manufacturing process might result  
43 in the need for developing new product families or platforms. Especially, the low level of  
44 cooperation between sales, engineering and manufacturing on this point can be seen as an  
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inherent weakness of all companies investigated. Engineering management does not become a management of engineering unless it integrates with sales, production, etc. to meet overall performance requirements.

Furthermore, in conjunction with the previous paragraph, a modular product design offers also possibilities for modular innovation, one of the four types of innovation that Henderson & Clark (1990) distinguish. The concept of architectural innovation offers the possibility to revolutionise product design and the possibility to look for other applications, e.g. in other product-market combinations. To manage this process, the Model for the Innovation Impact Point (Dekkers, 2005, pp. 306-308) is proposed to link the accumulation of incremental changes, component innovation and architectural innovation to the strategy for product market combinations. However, the architecture of a modular design will inhibit architectural innovation (see Henderson & Clark [1990]). Ultimately, an active management of the engineering process combined with this model will increase the innovative capability of engineering and manufacturing companies.

#### 4 CONCLUSIONS

The review of five cases on the application of the Order Entry Matrix and modular design demonstrates the strong intertwining between the product architecture and the operational control for both the manufacturing and the engineering processes. Traditionally not well researched, the case studies show that the application of the Order Entry Matrix to meet performance requirements (lead-time, product flexibility and productivity) has a strong impact on the engineering processes. The characteristics of engineering allow a limited range of interventions, esp. more difficult task allocation to engineers, putting more stress on adequate capacity management. Also, the “freedom” of engineers seems at stake. The

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7 management of the engineering process turns out to be weakly developed in industry and  
8 resistance to change persists in the implementation of more adequate operational control.  
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12 The framework for operations management of engineering, introduced in this paper,  
13 encompasses the recognition of Order Entry Points in the engineering processes, the  
14 standard working methods for the conversion of customer requirements into modules of a  
15 modular product architecture, the management of customer order activities and the separate  
16 development of new product architecture for future demands. Alternatively, a modular  
17 design increases the innovative capability of firms through architectural innovation. The  
18 base for integrated operations management of engineering, embedded within the total  
19 business processes, requires elaboration, mostly because by connecting different strands of  
20 research.  
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Table 1: Overview of case studies. The second columns indicates the types of products that the companies produce and next to it the main performance criteria for the studies. The fourth column reflects the impact of the in-depth study on the Order Entry Points. The two columns on the right list which engineering management and integration issues were encountered during the studies.

Case	Products	Scope of Study	Order Entry Points	Engineering Issues	Integration Issues
A	Equipment food industry (large custom-made equipment 10/yr)	Reduction overall lead-time (from 9 months to 6 months), wide variety of customer demands	Start of project: OSEP-4/COEP-5. After redesign: Basic/standard OSEP-3/COEP-5 (17/6 functions), Specials OSEP-4/COEP-5.	Draft assembly plan as standard documentation. Product architecture required extensive redesign. Resistance to change: manager of Engineering Department maintaining the status quo, introduced 7 years later.	Draft assembly plan
B	Rotary screen printing machines (textile printing) (250/yr)	Productivity, lead-time (from 6 to 2 weeks), flexibility	Start of project: OSEP-4/COEP-5. After redesign: OSEP-2/COEP-3/4/5	Redesign of product architecture necessary to facilitate new manufacturing organisation. Reduction of engineering efforts per order	Product configuration (standardised)
C	Display counters for retail (food) (500/yr)	Reduction overall lead-time (from 8 to 4 weeks), engineering effort not in balance with market prices	Start of project: 80% OSEP-4, 20% OSEP-3, COEP-4/5. After redesign: 80% OSEP-3, COEP-3/4.	Redesign of product architecture. Reduction of engineering lead-time from 3.5 weeks to 1.5 weeks: integration with sales.	Product configurator
D	Packaging machines (50/yr)	Reduction overall lead-time (from 12 to 8 weeks), flexibility for customer demands	Start of project: OSEP-4/COEP-3/4/5. After implementation: Basic/standard OSEP-3/COEP-3/4/5, Specials OSEP-4/COEP-4/5	Minor redesign of product architecture. Loop for detecting shifting market demands and decision-making.	Draft assembly plan
E	Plant automisation construction industry (5/yr)		Start of project: OSEP-4/COEP-5. After implementation: OSEP-3/OCEP-5	Modular and incremental pre-design to meet a wide variety of customer demands	Standard engineering (software). Standard production method

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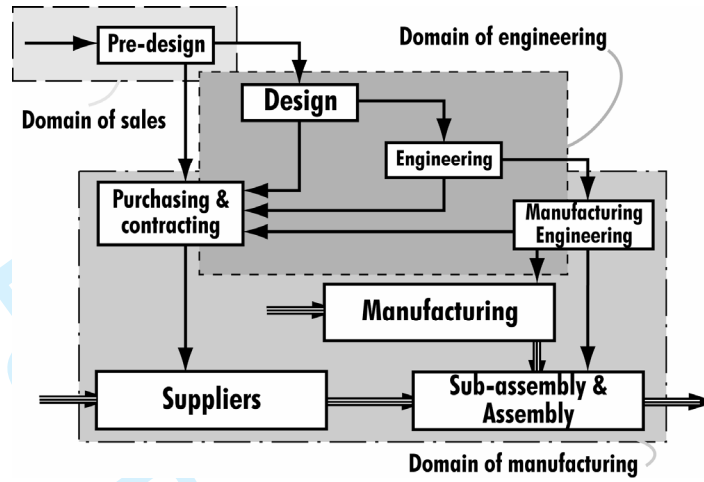


Figure 1: Simplified, generic total primary process. The total primary process consists of two flows: (1) the material and logistic flow in the domain of manufacturing and (2) the information flow, product and process data, related to product development and engineering..

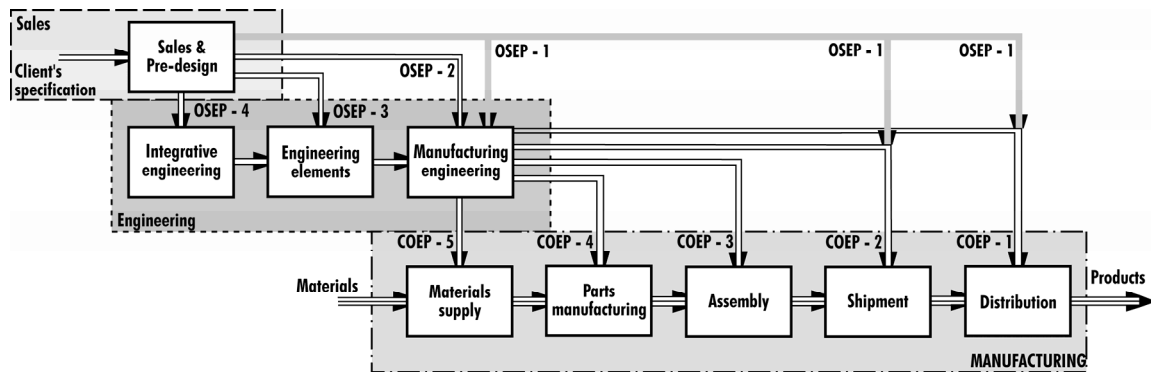


Figure 2: Position of the Order Entry Points in the primary process of design, engineering, manufacturing and logistics. To simplify the figure points of stock have been omitted. OSEP-1 (Order Specification Entry Point) indicates that customer requirements are directly transferred into production instructions, while OSEP-4 points to Engineering-to-Order. Similarly in the material flow: COEP-1 (Customer Order Entry Point) tells that orders are delivered directly from stock, while COEP-5 marks Make-to-Order.

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		COEP				
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Figure 3: Order Entry Matrix. The position in this matrix indicates the efforts required to fulfil an order. Products might consist of different components with different combinations of the Order Entry Points.

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Functions Variants	Basic	Standard	Option	Client requirements
One	Basic module			Special module
Limited		Standard module		
Mostly one			Optional module	

Figure 4: Grid for modular product architecture. The basic module is always part of a product. Standard modules are also needed but the configurations vary based on customer requirements. Specific customer requirements result in either pre-designed optional modules or special modules (designed per order).