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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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7 According to these approaches, management should consider the decisions for positioning
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9 the Order Entry Points to meet performance requirements adequately, often in combination
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11 with modular design.
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13 **1.1 Background**

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16 Most literature pays attention to the impact of the Order Entry Points (and the related
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18 modular design) on logistics and operations. Originally, Sharman (1984) introduced the
19
20 Order Entry Points for logistic control and Wemmerlöv (1984) pointed to the existence of
21
22 different modes of operation for Make-to-Stock, Make-to-Order and Assemble-to-Order.
23
24 These writings were quickly followed by others, like Hoekstra & Romme (1985), explicitly
25
26 introducing the Order Entry Points to improve logistic management in industrial
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28 companies. Meanwhile, it has been developed to address logistic management (e.g.
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30 Christopher & Towill, 2000; van Donk, 2001; de Haan et al., 2001; Vries et al., 1999;
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32 Wanke & Zinn, 2004), Supply Chain Management (like Croxton et al., 2001; Graves &
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34 Willems, 2000, Lee & Lau, 1999; Mason-Jones et al., 2000; Sabri & Beamon, 2000), IT
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36 applications (for example, Andries & Gelders, 1995, p. 36; Giesberts & van de Tang, 1992;
37
38 Sabri & Beamon, 2000), and outsourcing (e.g. van der Vlist et al., 1997). A stream of
39
40 literature sees Order Entry Points as concept for connecting the lean paradigm with the
41
42 agility of the supply chain (Christopher, 2000; Naylor et al., 1999). Others, like Mason-
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44 Jones et al. (2000) and Schuh et al. (1998), emphasise the strategic flexibility of modular
45
46 designs connected to the Order Entry Points; this flexibility has also been a cornerstone for
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48 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.
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16 Mikkola & Skjøtt-Larsen, 2004). While at the same time, most literature on modular design
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18 (e.g. Sanchez, 2004; Simpson et al., 2001; Stone et al., 2000) does not include
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20 manufacturing strategy or logistics as driver for the configuration of products. Riedel &
21
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
29
30 engineering. The initial case study resulting from Action Research into Strategic Capacity
31
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
37
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
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19 organisational structure with upstream Order Entry Points would prove beneficial.

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22 However, it remained unclear which impact these Order Entry Points would have on
23 control of engineering to meet customer demands and therefore this has been examined
24 separately (this was one of the remaining research topics mentioned by Bikker & Dekkers
25 [1994]). Nonetheless, engineering management cannot be separated from the
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implementation in manufacturing and logistics. Hence, the issues for engineering
management have been extracted from the reports of the five case studies. Since each case
study contains unique solutions, the research reported here focuses on commonalities with
respect to issues in engineering management; additionally, the subject of integration of
sales, engineering, manufacturing and logistics has been reviewed.

1.3 *Scope of Paper*

Consequently, this paper will address the link between engineering (including product
development) and manufacturing strategy and it will discuss the impact of the Order Entry
Points on the operations of engineering. This way it will connect modular design as an
engineering concept to the Order Entry Points. The publication will also provide a
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
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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
23
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
29
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.
46
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
11
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
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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
38
39 constructions makes it possible to apply already developed components and assemblies for
40
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
13
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
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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
31
32 opportunities for accepting orders. Olhager (2003) discusses the pros and cons for shifting
33
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 &
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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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35 [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
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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
37
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
5 engineering and manufacturing companies that produce on order (before the
6 implementation of the Order Entry Matrix). The issues for the engineering processes and
7 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;
18 the integrated improvement of the primary process to meet shifting performance
19 requirements stood at the heart of these studies. These four cases constitute industrial
20 companies that produce small-series to medium-sized series of equipment for industrial use,
21 mostly. Traditionally, engineering activities during the conversion from customer
22 requirements to manufacturing instructions resulted in lengthy lead-times, reduced
23 efficiency and difficult operational control. Although the specific solutions for the
24 companies varied, they all embodied the introduction of Order Entry Points and modular
25 design. The studies have resulted in improvement of the conflicting requirements of lead-
26 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
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4 standardised design and modular components has been developed to conduct the pre-design
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6 and initial stages of the engineering process. The proposal decreased the number of hours
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8 and decreased the lead-time. Because of the low number of projects and specific
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10 requirements it is not possible to assess the exact improvements; an estimate showed that
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12 the payback time, for the standardised design and the implementation, could be 1-1½ years.
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16 Additionally, the shift in the Order Entry Points implies a separation between the
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18 processing of customer orders and product development. Only in Case B this has not been
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20 implemented due to the nature of the products, and due to the assessment of the company
21
22 that their basic design would not need any upgrades for a while. In the old situations the
23
24 engineering of customer orders and product development were intertwined in the skills and
25
26 capabilities of individual engineers. The working methods introduced by modular design
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28 entail the division of the engineering process in three separate processes: (a) the
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30 engineering of special modules, (b) the preparation of documentation for manufacturing in
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32 case of OSEP-3 and OSEP-2, and (c) the development of new product designs. Yet, the
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34 strict separation of these processes (and their control) has not been implemented in any of
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36 the engineering departments; neither were engineers purely allocated to products or product
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38 families.
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46 Furthermore, the process for managing market demands becomes paramount. A modular
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48 product architecture improves the response to specific customer demands at the expense of
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50 product flexibility. Developing each product on its own offers the best flexibility to the
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52 market; however, it does not solve the problems related to productivity and lead-time. The
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54 architecture of the product limits the implementation of any customer requirement; hence,
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56 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
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23 incorporate engineering efforts in orders, the implementation of the Order Entry Points
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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
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29 configuration system has been developed for assisting sales representatives while in the
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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** 42 43

44 At two companies, the engineering department resisted to the change the Order Entry
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46 Points would bring along. In Case A, the implementation was delayed until the engineering
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48 manager left the company. In Case E, the project managers, which are engineers
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50 themselves, did initially not acknowledge the advantages of modular design; only when it
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52 became clear that the excess of project budgets was related to an excess of engineering
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54 efforts, the modular design and the standard working method were favoured. The different
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56 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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7 change.

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10 This resistance comes along with the disconnection of operations (processing customer
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12 orders within the bandwidth of the modular design) and product development in
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14 engineering. One group should concentrate on the processing of orders and one on product
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16 development. The implementation of this working method did not properly take place in
17
18 any of the companies, although Gulati & Eppinger (1996) indicate the close relationship
19
20 between product configuration and organisational structure. The relative size of the
21
22 engineering departments in the companies investigated and the specific knowledge of
23
24 engineers make it more difficult to approach engineering management similarly as
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26 operations management.
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31 In addition, the management of customers' requirements calls for an early detection of
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33 shifts and trends. Shifting trends and demands should lead to decision-making on optional
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35 modules, basic modules, conversion from special modules to optional modules and
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37 redesign of the product architecture (upgrade or new design). A loop to do so would
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39 suffice; this would act as a feedforward before the order processing to avoid an inflow of
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41 too many orders as custom design. Additionally, it would be necessary to include a
42
43 detection of trends in customer orders to anticipate on future demands. This detection of
44
45 shifts and the active management of the engineering process would also require the design
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47 of subsequent product families and platforms. Accumulation of customer demands and
48
49 feedback from the routine engineering process and the manufacturing process might result
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51 in the need for developing new product families or platforms. Especially, the low level of
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53 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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6 become a management of engineering unless it integrates with sales, production, etc. to
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8 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
21
22 Innovation Impact Point (Dekkers, 2005, pp. 306-308) is proposed to link the accumulation
23
24 of incremental changes, component innovation and architectural innovation to the strategy
25
26 for product market combinations. However, the architecture of a modular design will
27
28 inhibit architectural innovation (see Henderson & Clark [1990]). Ultimately, an active
29
30 management of the engineering process combined with this model will increase the
31
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
42
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
48
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

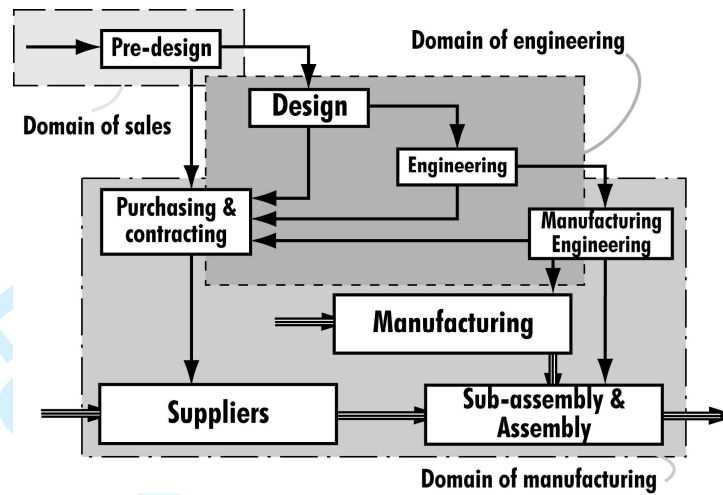


Figure 1: Simplified, generic total primary process. The total primary process consists of two flows: (1) the material and logistic flow in the domain of manufacturing and (2) the information flow, product and process data, related to product development and engineering.

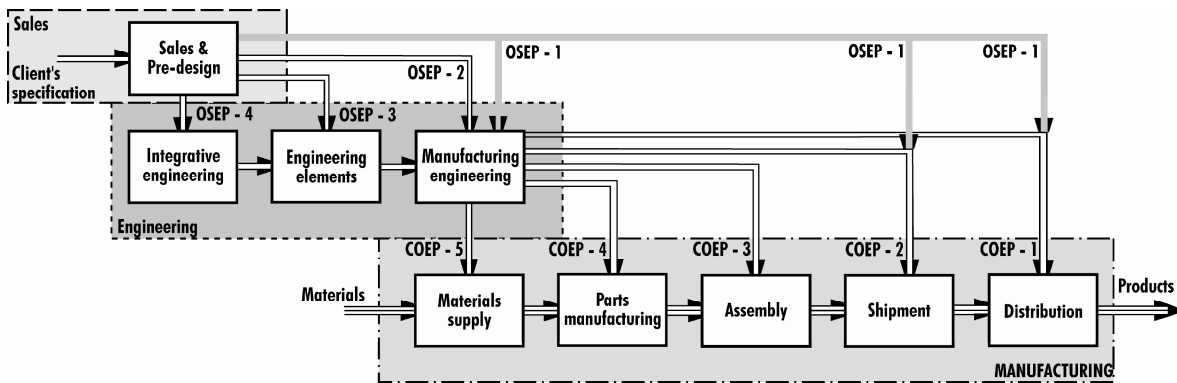


Figure 2: Position of the Order Entry Points in the primary process of design, engineering, manufacturing and logistics. To simplify the figure points of stock have been omitted. OSEP-1 (Order Specification Entry Point) indicates that customer requirements are directly transferred into production instructions, 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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OSEP	1					
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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 52 **1.2 Research Methodology**

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55 In this context, five manufacturing companies have been examined on the impact of Order
56 Entry Points; the scope did include manufacturing management and engineering
57 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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40 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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28 [Insert Figure 1 about here]
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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
17
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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- 24 • the availability of the product specification for production;
 - 25 • the permitted lead-time;
 - 26 • 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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38 [Insert Figure 4 about here]
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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-
16
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
20
21 range of basic, standard and standard optional modules. By configuring the product
22
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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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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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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8 Requirements outside the scope of the requirements should be treated as specials; processes
9 should be in place to avoid overdraft on these types of projects (e.g. easier to sell for sales
10 representatives but more costly to make). Although recognised as key point of strategy,
11 none of the companies, except A, did actively control the tuning between sales and
12 engineering on this point.
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19 That brings us to the issues of integration between sales, engineering, manufacturing and
20 logistics. Since these companies produce small series to medium-sized series and often
21 incorporate engineering efforts in orders, the implementation of the Order Entry Points
22 covers mostly the logistic issues. That leaves the amalgamation of sales, engineering and
23 manufacturing as remaining issue. From Table 1 it appears that in only one case a product
24 configuration system has been developed for assisting sales representatives while in the
25 other cases the integration focuses more on standard procedures. Case C has also the largest
26 series produced per year, may be the reason why such becomes feasible. In the other four
27 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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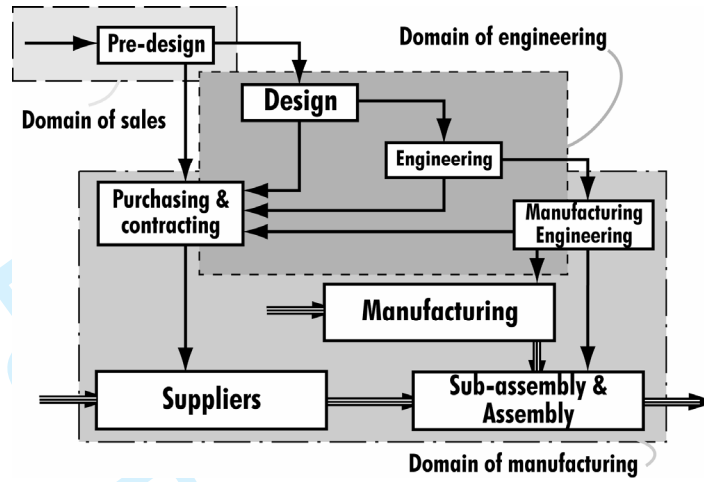


Figure 1: Simplified, generic total primary process. The total primary process consists of two flows: (1) the material and logistic flow in the domain of manufacturing and (2) the information flow, product and process data, related to product development and engineering..

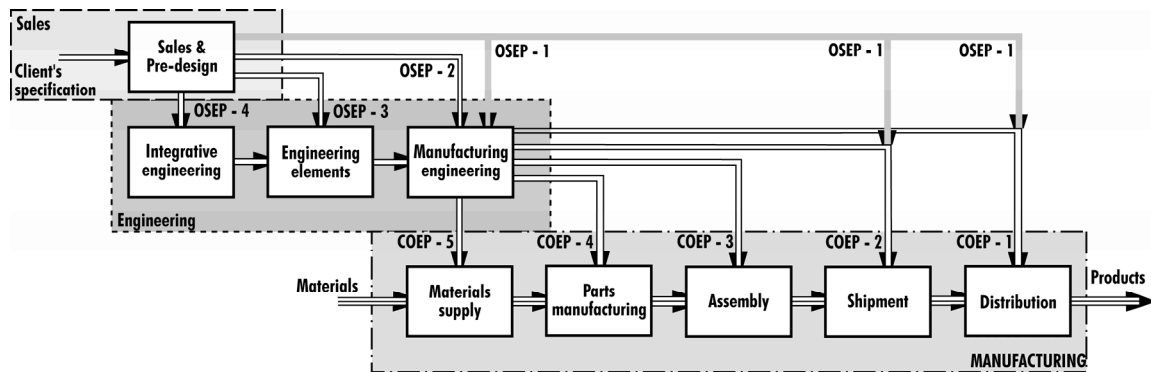


Figure 2: Position of the Order Entry Points in the primary process of design, engineering, manufacturing and logistics. To simplify the figure points of stock have been omitted. OSEP-1 (Order Specification Entry Point) indicates that customer requirements are directly transferred into production instructions, 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				
		1	2	3	4	5
OSEP	1					
	2			■		
	3			■	■	
	4					■

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).