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

Journal:	*International Journal of Production Research*
Manuscript ID:	TPRS-2005-IJPR-0481
Manuscript Type:	Original Manuscript
Date Submitted by the Author:	29-Nov-2005
Complete List of Authors:	Dekkers, Rob; Delft University of Technology, Section Technology, Strategy and Entrepreneurship
Keywords:	ENGINEERING MANAGEMENT, DESIGN FOR MANUFACTURE, MASS CUSTOMIZATION
Keywords (user):	Order Entry Points, Architectural innovation

Engineering Management and the Order Entry Point

Rob Dekkers

Delft University of Technology, Jaffalaan 5, 2628 BX Delft, the Netherlands

E-mail: dek.rob@gmail.com, ph.: + 31 (15) 278 36 21, fax: + 31 (15) 278 71 55

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

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

1.1 Background

Most literature pays attention to the impact of the Order Entry Points (and the related modular design) on logistics and operations. Originally, Sharman (1984) introduced the Order Entry Points for logistic control and Wemmerlöv (1984) pointed to the existence of different modes of operation for Make-to-Stock, Make-to-Order and Assemble-to-Order. These writings were quickly followed by others, like Hoekstra & Romme (1985), explicitly introducing the Order Entry Points to improve logistic management in industrial companies. Meanwhile, it has been developed to address logistic management (e.g. Christopher & Towill, 2000; van Donk, 2001; de Haan et al., 2001; Vries et al., 1999; Wanke & Zinn, 2004), Supply Chain Management (like Croxton et al., 2001; Graves & Willems, 2000, Lee & Lau, 1999; Mason-Jones et al., 2000; Sabri & Beamon, 2000), IT applications (for example, Andries & Gelders, 1995, p. 36; Giesberts & van de Tang, 1992; Sabri & Beamon, 2000), and outsourcing (e.g. van der Vlist et al., 1997). A stream of literature sees Order Entry Points as concept for connecting the lean paradigm with the agility of the supply chain (Christopher, 2000; Naylor et al., 1999). Others, like Mason-Jones et al. (2000) and Schuh et al. (1998), emphasise the strategic flexibility of modular designs connected to the Order Entry Points; this flexibility has also been a cornerstone for literature on product families and platforms (like Meyer & Utterback, 1993). Generally speaking, much emphasis is given to consequences for order processing, stock control, stock replenishment and performance improvement.

But what about the modular design and its link to engineering management? Within the strand of literature on logistics and Supply Chain Management, the modular design is mostly taken either as starting point or as consequence of the Order Entry Points (e.g. Mikkola & Skjøtt-Larsen, 2004). While at the same time, most literature on modular design (e.g. Sanchez, 2004; Simpson et al., 2001; Stone et al., 2000) does not include manufacturing strategy or logistics as driver for the configuration of products. Riedel & Pawar (1998) highlight that the concepts of design and manufacturing are not linked in literature and that the interaction of product design and manufacturing strategy is under-researched. Spring & Dalrymple (2000) come to the same conclusion when examining two cases of product customisation: manufacturing issues get little attention during design and engineering. The initial case study resulting from Action Research into Strategic Capacity Management (Dekkers, 2003) demonstrates this notion as well. For the Order Entry Points, Rudberg & Wikner (2004) distinguish the engineering and production dimension in their conceptual paper, while earlier work by Bikker & Dekkers (1994) elaborates on the consequences for engineering. Consequently, most literature has ignored the vital link between engineering processes and manufacturing strategy and hardly discusses the impact on operations management of engineering.

1.2 Research Methodology

In this context, five manufacturing companies have been examined on the impact of Order Entry Points; the scope did include manufacturing management and engineering management (product development in these companies has been embedded in the engineering department). The theory of modular design leading to a coherent approach to product architectures originates from earlier research (Bikker, 1992; van der Sterre, 1992). Logistic implications and a proposal for control have been discussed in Dekkers & Sopers (2001). The earlier research shows the successful implementation of the concept though it implies that companies have to adapt their operation's practices and systems. Action Research in all five case studies – with the findings in separate reports - revealed that a new organisational structure with upstream Order Entry Points would prove beneficial.

However, it remained unclear which impact these Order Entry Points would have on control of engineering to meet customer demands and therefore this has been examined separately (this was one of the remaining research topics mentioned by Bikker & Dekkers [1994]). Nonetheless, engineering management cannot be separated from the 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 will analyse the issues related to the implementation in engineering management. The added value is the disclosure of a field not well-studied in literature.

The paper will start with a description of the processes within industrial companies, directed at the engineering and manufacturing processes. Section 2 links these processes to the Order Entry Points mainly based on the previous publications, which relate closely to other literature in this field; however, the benefit is the distinction of Order Entry Points for both production and engineering processes. For some readers these theories might prove common ground. Section 3 introduces the theoretical framework for engineering management by the link to the Order Entry Points. This section presents the five case studies conducted within this framework and reports on the findings of the research into engineering management. Section 4 concludes the paper and displays the recommendations following from this research, which enables companies to cope with the contemporary challenges for performance and strategy more effectively caused by the trends of increasing variety and customisation.

2. ORDER ENTRY POINTS

That the current trend of customisation affects the control of operations within industrial companies leaves no doubt. Lampel & Mintzberg (1996) demonstrate the change of the demand by clients and the penetration of this demand into the organisation. Child et al. (1991) note that in some cases, companies attribute as much as 30% of their costs to product variety, while these variations account for as little as 3% of sales. Wüpping (1998) notes that especially during difficult times companies tend to accept any customer requirement not to leave any space to competitors. This illustrates the impact of the strategic choice on the performance of companies with the continuum of strategic choice ranging from pure standardisation to pure customisation. Pure standardisation leaves no room for differentiation, segmented standardisation may provide different distribution services or channels to different customer segments, customised standardisation encompasses final assembly of modules according to specific customer requirements, tailored customisation includes customer-specific components and modules in the final assembly, and pure customisation covers all specific process to meet unique customer requirements. According to Lampel & Mintzberg (1996) these five types, especially the trend for standardised customisation, effects the way anyone looks at organisations and the control of the primary process.

[Insert Figure 1 about here]

Figure 1 describes the design processes, engineering processes and manufacturing processes; it distinguishes two main processes: the product information flow and the material flow. During the product information flow, client requirements transform into specifications and instructions for manufacturing. The material flow concerns the manufacturing of parts and the assembly of the final products from parts and purchased parts. The *Sales Process* of this model translates the client's requirements into specifications for engineering. The sales process is not only performed by the sales force but might involve other personnel, such as sales engineers, project engineers, engineers and technical buyers from the customer. The *Engineering Process* transforms the specifications from the sales process into standards and information for production, i.e., drawings, assembly instructions, etc. Before using these standards and information, the manufacturing engineering function adds production instructions for the actual production process. The

Manufacturing Process, including purchasing materials and parts, converts these materials and parts into products ready for distribution and delivery.

When the delivery times for a company decrease, the turnaround for logistic control arrives if the lead-time for delivery of specific orders approaches or becomes shorter then the throughput time for engineering and manufacturing. Especially in the case that clients require specials or specific requirements, they have a few options for the product information flow and the material flow. For the product information flow, companies might reduce further on lead-time through:

- introducing new methods of working;
- concurrent and simultaneous engineering;
- reuse of constructions.

The introduction of new methods, concurrent and simultaneous engineering will not always have the desired effect. The options will reduce delivery time but they approach the specific client requirements from a project-oriented point of view (Dekkers, 1997). The reuse of constructions makes it possible to apply already developed components and assemblies for a new client order.

2.1 Order Entry Points

[Insert Figure 2 about here]

Within the material flow companies have only as an option to manufacture on stock, located on an appropriate point within the manufacturing process. This point of stock is called the Custom Order Entry Point. The point where an order enters the material flow, the Custom Order Entry Point (COEP), determines which specific activities have to be undertaken after the start of a custom order (Figure 2); please note that the points of stock have been omitted from the figure. Although instructions have to be prepared by manufacturing engineering for any of the subprocesses of production, the effect of the various entry points is different. On the extreme side where final products are kept at stock, the effect of an order restricts itself to the distribution of the finished product (COEP-1 equals Ship-to-Stock). The second COEP indicates that shipment processes have to be included into the specific activities (Make-to-Stock). When assembly activities belong to the execution of an order the COEP positions itself at point 3 (Assemble-to-Order) and in the case of manufacturing of parts at point 4 (Make-to-Order). Engineering-on-order will mostly result in purchasing specific parts and materials for that order and enters the manufacturing process at point 5 (Buy-to-Order). Downstream of the COEP no stocks should be available for sales and that the logistic decisions mostly affect the risks and opportunities for accepting orders. Olhager (2003) discusses the pros and cons for shifting the Order Entry Point forwards and backwards. Upstream decisions direct themselves at the risks coming along with investing in stocks. The COEP represents in most cases the latest stock point in the logistic chain; from this point on client's orders have to be delivered. Before this entry point, the forecasts of the orders guides the planning of manufacturing activities; for example, the production planning might be based on MRP-II (Andries & Gelders, 1995, p.36; de Haan et al., 2001, p. 107). After this entry point, the emphasis on control of manufacturing shifts to lead-time and flexibility since specific customer requirements have to be met (the agility of the supply chain).

Thus, the dilemma for the engineering process remains how to reduce costs by reuse of designs and at the same time reduce total lead-time while clients have specific requirements. Similarly, to the material flow, the product information flow has a point where a custom order enters the process. The product information flow generates the related specifications and instructions for the manufacturing process. The position of the Order Specification Entry Point (OSEP) indicates the amount of engineering work before any order is specified for manufacturing and logistics. The more the design and configuration has been developed in advance, the less the amount of engineering work that remains to be done for processing a specific order. When the client accepts an order for an already defined product, the product information is then ready for manufacturing. In such a case, the order information is directly transferred to production engineering or shipment and distribution (OSEP-1 in Figure 2). Position 2 of the OSEP indicates that production engineering has to transform the standard information from engineering into information for manufacturing; the order does not require any specific engineering. Either Engineering-to-Order leads to adaptations of existing configurations (OSEP-3) or a total dedicated design (OSEP-4). The product architecture has a strong influence on the position of this point. Any change in requirements from clients that leads to a new design or similar effects, moves the position of the OSEP to point 4 with its lead-times. The points OSEP-1 and -2 indicate how successful a company is by reusing configurations.

2.2 Product Flexibility and the Order Entry Matrix

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

Figure 3). Different products and constructions may require different positions of these points in the Order Entry Matrix. When an OSEP for a certain product architecture allows acceleration of the order processing during the specification process, management has still freedom in positioning the COEP.

[Insert Figure 3 about here]

The choice of the COEP determines mostly the performance of manufacturing and logistics. The decision for the COEP one derives from:

- the availability of the product specification for production;
- the permitted lead-time;
- the frequency of expected sales of individual modules.

The Order Entry Matrix reveals which measures to take for reducing the lead-time and increasing the productivity and flexibility. Moving the Entry Points downstream will reduce the lead-times and improve the reuse of product configurations.

When a company has different OSEP/COEP combinations that might be attributed to three reasons. Firstly, some product architectures and components require only assembly for a specific order while at the same time specific materials have to be purchased. Secondly, special requirements influence only part of the total design; this implies that some parts are not affected while other products or components need a redesign to meet customer demands. Finally, the whole range of products of a company can have different combinations; standard products have a different combination than products with much engineering work.

The pull from the market for dedicated variety as a result from customer demands should be regarded as given. The product flexibility can be illustrated by positioning each variant within the Order Entry Matrix. Before doing so, the product has to be broken down in components called modules. This product architecture follows the definition of modules as presented by Bikker & van der Heyden (1987); Weinbrenner & Ehrlenspiel (1993) have presented a similar breakdown in modules, sub-assemblies, etc. In Figure 4 we see different modules as part of the total product family. One will find basic modules in each product; client specifications do not influence the design of this type of module. Standard modules refer to modules from which different designs are available and which have to be used in each product. Examples of such a module might be the choice for a 110V or 230V power supply. Standard optional modules are features and additions that the client might choose from a short-list. When the client specification cannot be related to these modules, a special module might be created.

[Insert Figure 4 about here]

When applying the Order Entry Matrix, a product family can be configured consisting of assemblies and parts. The sales and engineering process should direct client requirements to standard modules, standard option modules and specials. By minimising the use of special modules, the dilemma of variants and variety will be met. Such a family of products configured in modules each serving an original function or sub-function provides one of the most promising answers to the dilemma. On this matter, Eekels (1993) has already pointed out that the relationship between client and supplier exists on the exchange of functions. Similarly, Meyer & Utterback (1993) describe the core capability as keystone for configuring products and product families. In that view, the underlying value of a product family is represented by the core capabilities of products and the value for the customer; both the core capability and the value resemble Eekels' description of function.

3. ENGINEERING AND ORDER ENTRY POINTS

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

3.1 Impact of Modular Design

The most effective way of managing the engineering process is by modularisation. This topic has been widely investigated but weakly linked to the Order Entry Points in that same literature. The OSEP indicates the type of work and the amount of work to be done for a customer order. For example, a reduction in engineering efforts will only be possible if the product design consists of standard modules, basic modules and (sometimes) optional modules. The foremost effect of the Order Entry Matrix and the belonging modular design constitutes the different modus 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 engineering and manufacturing companies that produce on order (before the implementation of the Order Entry Matrix). The issues for the engineering processes and management have been listed in the last column of Table 1.

[Insert Table 1 about here]

The first four cases concerned both the engineering process and the manufacturing process; the integrated improvement of the primary process to meet shifting performance requirements stood at the heart of these studies. These four cases constitute industrial companies that produce small-series to medium-sized series of equipment for industrial use, mostly. Traditionally, engineering activities during the conversion from customer requirements to manufacturing instructions resulted in lengthy lead-times, reduced efficiency and difficult operational control. Although the specific solutions for the companies varied, they all embodied the introduction of Order Entry Points and modular design. The studies have resulted in improvement of the conflicting requirements of lead-time, product flexibility and productivity.

The fifth case study did focus on the engineering process. The company executed orders for the construction industry, mainly by producing equipment for plants. The company's competitive advantage was to deliver custom-made equipment, in contrast to the competitors that delivered modular designs. Additionally, the analysis of five projects revealed that the losses amounted up to 20% per project due to an excess of engineering hours. This excess could be avoided by a more standardised operating procedure for the design and engineering of the products (based on small increments, that way approaching tailored design), in a way moving towards OSEP-1. A computer program based on a standardised design and modular components has been developed to conduct the pre-design and initial stages of the engineering process. The proposal decreased the number of hours and decreased the lead-time. Because of the low number of projects and specific requirements it is not possible to assess the exact improvements; an estimate showed that the payback time, for the standardised design and the implementation, could be 1-1½ years.

Additionally, the shift in the Order Entry Points implies a separation between the processing of customer orders and product development. Only in Case B this has not been implemented due to the nature of the products, and due to the assessment of the company that their basic design would not need any upgrades for a while. In the old situations the engineering of customer orders and product development were intertwined in the skills and capabilities of individual engineers. The working methods introduced by modular design entail the division of the engineering process in three separate processes: (a) the engineering of special modules, (b) the preparation of documentation for manufacturing in case of OSEP-3 and OSEP-2, and (c) the development of new product designs. Yet, the strict separation of these processes (and their control) has not been implemented in any of the engineering departments; neither were engineers purely allocated to products or product families.

Furthermore, the process for managing market demands becomes paramount. A modular product architecture improves the response to specific customer demands at the expense of product flexibility. Developing each product on its own offers the best flexibility to the market; however, it does not solve the problems related to productivity and lead-time. The architecture of the product limits the implementation of any customer requirement; hence, in a certain way the product architecture decreases the product flexibility. Then it becomes more important to incorporate a well-defined set of requirements into the basic design. Requirements outside the scope of the requirements should be treated as specials; processes should be in place to avoid overdraft on these types of projects (e.g. easier to sell for sales representatives but more costly to make). Although recognised as key point of strategy, none of the companies, except A, did actively control the tuning between sales and engineering on this point.

That brings us to the issues of integration between sales, engineering, manufacturing and logistics. Since these companies produce small series to medium-sized series and often incorporate engineering efforts in orders, the implementation of the Order Entry Points covers mostly the logistic issues. That leaves the amalgamation of sales, engineering and manufacturing as remaining issue. From Table 1 it appears that only in one case a product configuration system has been developed for assisting sales representatives while in the other cases the integration focuses more on standard procedures. Case C has also the largest series produced per year, may be the reason why such becomes feasible. In the other four cases, the companies do not see any need to go beyond the standardised working methods.

3.3 Discussion of Findings

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

This resistance comes along with the disconnection of operations (processing customer orders within the bandwidth of the modular design) and product development in engineering. One group should concentrate on the processing of orders and one on product development. The implementation of this working method did not properly take place in any of the companies, although Gulati & Eppinger (1996) indicate the close relationship between product configuration and organisational structure. The relative size of the engineering departments in the companies investigated and the specific knowledge of engineers make it more difficult to approach engineering management similarly as operations management.

In addition, the management of customers' requirements calls for an early detection of shifts and trends. Shifting trends and demands should lead to decision-making on optional modules, basic modules, conversion from special modules to optional modules and redesign of the product architecture (upgrade or new design). A loop to do so would suffice; this would act as a feedforward before the order processing to avoid an inflow of too many orders as custom design. Additionally, it would be necessary to include a detection of trends in customer orders to anticipate on future demands. This detection of shifts and the active management of the engineering process would also require the design of subsequent product families and platforms. Accumulation of customer demands and feedback from the routine engineering process and the manufacturing process might result in the need for developing new product families or platforms. Especially, the low level of cooperation between sales, engineering and manufacturing on this point can be seen as an 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 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.

REFERENCES

Andries, B. and Gelders, L., Time-based manufacturing logistics. *Logistics Information Management*, 1995, 8(3), 30-36.

Bikker, H., Technisch management van produktwijzigingen, Deel 1: Produktwijzigingen aan de lopende band. *de Constructeur*, 1992, 92(4), 22-30.

Bikker, H. and Dekkers, R., The Order Entry Matrix: Keystone for Productivity of Design and Manufacturing, in *2nd International Conference Product Development Management on New Approaches to Development and Engineering*, 1994, pp. 44-58.

Bikker, H. and Heyden, W. van der, Systematic Product Breakdown as a major tool for productivity improvement. *International Journal of Production Research*, 1987, 25(11), 1635-1644.

Child, P., Diederichs, R., Sanders, F.-H. and Wisnioswki, S., SMR Forum: The Management of Complexity. *Sloan Management Review*, 1991, 33(1), 73-80.

Christopher, M., The Agile Supply Chain. *Industrial Marketing Management*, 2000, 29(1), 37-44.

Christopher, M. and Towill, D. R., Supply chain migration from lean and functional to agile and customised. *Supply Chain Management*, 2000, 5(4), 206-213.

Croxton, K. L., Garcia-Dastugue, S. J., Lambert, D. M. and Rogers, D. S., The Supply Chain Management Processes. *The International Journal of Logistics Management*, 2001, 12(2), 13-36.

Dekkers, R., Concurrent Engineering and Project Management as Tools for Product Development, in *4th International Product Development Management Conference*, 1997, pp. 241-250.

Dekkers, R., Strategic Capacity Management: Balancing Technological Demands and Performance Criteria. *Journal of Materials Processing Technology*, 2003, 139(1-3), 385-393.

Dekkers, R., *(R)Evolution, Organizations and the Dynamics of the Environment*, 2005 (Springer: New York).

Dekkers, R. and Sopers, F. P. M., Production Control and the Order Entry Point, in *16th International Conference on Production Research*, 2001 [CD-ROM].

Donk, D. P. van, Make to stock or make to order: The decoupling point in the food processing industries. *International Journal of Production Economics*, 2001, 69(3), 297-306.

Eekels, J., Ontwerpen en het realiseren van waarden. *de Ingenieur*, 1993, (6), 44-47.

Furukawa, Y., Paradigms for Future Manufacturing Systems (keynote), in *9th Annual Conference CIM Europe*, Amsterdam, 1993.

Giesberts, P. M. J. and Tang, L. van der, Dynamics of the customer order decoupling point: impact on information systems for production control. *Production Planning & Control*, 1992, 3(3), 300-313.

Gulati, R. K. and Eppinger, S. D., The Coupling of Product Architecture and Organizational Structure Decisions. Working Paper 3906, MIT Sloan School of Management, 1996.

Graves, S. C. and Willems, S. P., Optimizing Strategic Safety Stock Placement in Supply Chains. *Manufacturing & Service Operations Management*, 2000, 2(1), 68-83.

Haan, J. de, Yamamoto, M. and Lovink, G., Production planning in Japan: Rediscovering lost experiences or new insights? *International Journal of Production Economics*, 2001, 71(1-3), 101-109.

Henderson, R. and Clark, K., Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly*, 1990, 35(1), 9-30.

Hoekstra, S. and Romme, J. H. J. M., *Op weg naar integrale logistieke structuren*, 1985 (Kluwer/NIVE: Deventer).

Lampel, J. and Mintzberg, H., Customizing Customization. *Sloan Management Review*, 1996, 38(1), 21-30.

Lee, W. B. and Lau, H. C. W., Factory on demand: the shaping of an agile production network. *International Journal of Agile Management Systems*, 1999, 1(2), 83-87.

Mason-Jones, R., Naylor, B. and Towill, D. R., Engineering the leagile supply chain. *International Journal of Agile Management Systems*, 2000, 2(1), 54-61.

Meyer, M. H. and Utterback, J. M., The Product Family and the Dynamics of Core Capability. *Sloan Management Review*, 1993, 34(3), 29-47.

Mikkola, J. H. and Skjøtt-Larsen, T., Supply-chain integration: implications for mass customization and postponement strategies. *Production Planning & Control*, 2004, 15(4), 352-361.

Naylor, J. B., Naim, M. M. and Berry, D., Leagility: Integrating the lean and agility manufacturing paradigms in the total supply chain. *International Journal of Production Economics*, 1999, 62(1-2), 107-118.

Olhager, J., Strategic positioning of the order penetration point. *International Journal of Production Economics*, 2003, 85(3), 319-329.

Riedel, J. and Pawar, K. S., The strategic choice of simultaneous versus sequential engineering for the introduction of new products. *International Journal of Technology Management*, 1998, 6(3/4), 321-334.

Rudberg, M. and Wikner, J., Mass customization in terms of the customer order decoupling point. *Production Planning & Control*, 2004, 15(4), 445-458.

Sabri, E. H. and Beamon, B. M., A Multi-Objective Approach to Simultaneous Strategic and Operational Planning in Supply Chain Design. *Omega*, 2000, 28(5), 581-598.

Sanchez, R., Creating Modular Platforms for Strategic Flexibility. *Design Management Review*, 2004, 15(1), 58-67.

Schuh, G., Schwenk, U. and Speth, C., Komplexitätsmanagement im St. Galler Management-Konzept. *io Management*, 1998, (3), 78-85.

Sharman, G., The rediscovery of logistics. *Harvard Business Review*, 1984, 62(5), 71-80.

Simpson, T. W., Maier, J. R. A. and Mistree, F., Product platform design: method and application. *Research in Engineering Design*, 2001, 13(1), 2-22.

Spring, M. and Dalrymple, J. F., Product customisation and manufacturing strategy. *International Journal of Operations & Production Management*, 2000, 20(4), 441-467.

Sterre, A. H. J. van der, Technisch management van produktwijzigingen, Deel 2: Produktwijziging en logistiek. *de Constructeur*, 1992, 92(5), 50-54.

Stone, R. B., Wood, K. L. and Crawford, R. H., A heuristic method for identifying modules for product architectures. *Design Studies*, 2000, 21(1), 5-31.

Vlist, P. v. d., Hoppenbrouwers, J. J. E. M. and Hegge, H. M. H., Extending the enterprise through multi-level supply control. *International Journal of Production Economics*, 1997, 53(1), 35-42.

Vries, G. de, Bertrand, J. W. M. and Vissers, J. M. H., Design requirements for health care production control systems. *Production Planning & Control*, 1999, 10(6), 559-569.

Wanke, P. F. and Zinn, W., Strategic logistics decision making. *International Journal of Physical Distribution & Logistics Management*, 2004, 34(6), 466-478.

Weinbrenner, V. and Ehrlenspiel, K., Produktlogik, Ein Hilfsmittel zur Automatisierung von Varianten- und Anpassungskonstruktionen, in *International Conference on Engineering Design*, 1993, pp. 1594-1601.

Wemmerlöv, U., Assemble-to-Order Manufacturing: Implications for Materials Management. *Journal of Operations Management*, 1984, 4(4), 347-368.

Wüpping, J., Logistikgerechte Produktstrukturen bei marktorientierter Variantenvielfalt,. *io Management*, 1998, (1/2), 76-81.

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

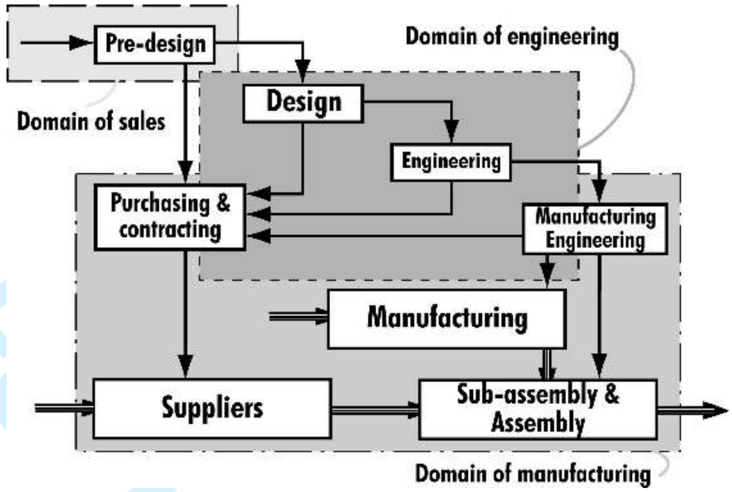

Figure 1: Simplified, generic total primary process. The total primary process consists of two flows: (1) the material and logistic flow in the domain of manufacturing and (2) the information flow, product and process data, related to product development and engineering.

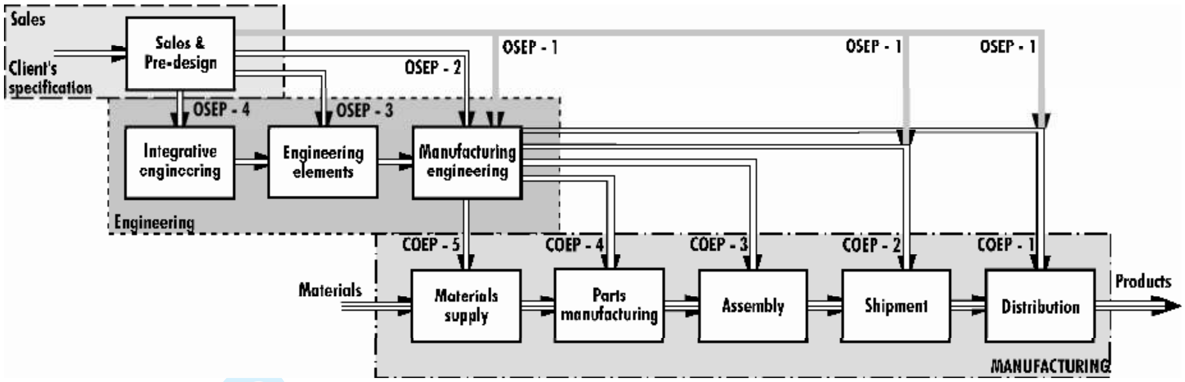

Figure 2: Position of the Order Entry Points in the primary process of design, engineering, manufacturing and logistics. To simplify the figure points of stock have been omitted. OSEP-1 (Order Specification Entry Point) indicates that customer requirements are directly transferred into production instructions,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

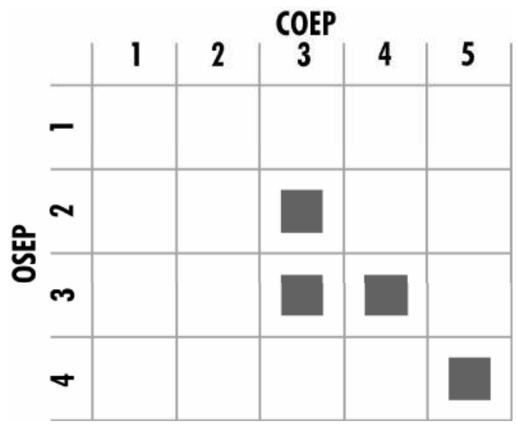

Figure 3: Order Entry Matrix. The position in this matrix indicates the efforts required to fulfil an order. Products might consist of different components with different combinations of the Order Entry Points.

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

Rob Dekkers

Delft University of Technology, Jaffalaan 5, 2628 BX Delft, The Netherlands

E-mail: r.dekkers@tbm.tudelft.nl, ph.: + 31 (15) 278 36 21, fax: + 31 (15) 278 71 55

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

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

1.1 Background

Most literature pays attention to the impact of the Order Entry Points (and the related modular design) on logistics and operations. Originally, Sharman (1984) introduced the Order Entry Points for logistic control and Wemmerlöv (1984) pointed to the existence of different modes of operation for Make-to-Stock, Make-to-Order and Assemble-to-Order. These writings were quickly followed by others, like Hoekstra & Romme (1985), explicitly introducing the Order Entry Points to improve logistic management in industrial companies. Meanwhile, it has been developed to address logistic management (e.g. Christopher & Towill, 2000; van Donk, 2001; de Haan et al., 2001; Vries et al., 1999; Wanke & Zinn, 2004), Supply Chain Management (like Croxton et al., 2001; Graves & Willems, 2000, Lee & Lau, 1999; Mason-Jones et al., 2000; Sabri & Beamon, 2000), IT applications (for example, Andries & Gelders, 1995, p. 36; Giesberts & van de Tang, 1992; Sabri & Beamon, 2000), and outsourcing (e.g. van der Vlist et al., 1997). A stream of literature sees Order Entry Points as concept for connecting the lean paradigm with the agility of the supply chain (Christopher, 2000; Naylor et al., 1999). Others, like Mason-Jones et al. (2000) and Schuh et al. (1998), emphasise the strategic flexibility of modular designs connected to the Order Entry Points; this flexibility has also been a cornerstone for literature on product families and platforms (like Meyer & Utterback, 1993). Generally speaking, much emphasis is given to consequences for order processing, stock control, stock replenishment and performance improvement.

But what about the modular design and its link to engineering management? Within the strand of literature on logistics and Supply Chain Management, the modular design is mostly taken either as starting point or as consequence of the Order Entry Points (e.g. Mikkola & Skjøtt-Larsen, 2004). While at the same time, most literature on modular design (e.g. Sanchez, 2004; Simpson et al., 2001; Stone et al., 2000) does not include manufacturing strategy or logistics as driver for the configuration of products. Riedel & Pawar (1998) highlight that the concepts of design and manufacturing are not linked in literature and that the interaction of product design and manufacturing strategy is under-researched. Spring & Dalrymple (2000) come to the same conclusion when examining two cases of product customisation: manufacturing issues get little attention during design and engineering. The initial case study resulting from Action Research into Strategic Capacity Management (Dekkers, 2003) demonstrates this notion as well. For the Order Entry Points, Rudberg &Wikner (2004) distinguish the engineering and production dimension in their conceptual paper, while earlier work by Bikker & Dekkers (1994) elaborates on the consequences for engineering. Consequently, most literature has ignored the vital link between engineering processes and manufacturing strategy and hardly discusses the impact on operations management of engineering.

1.2 Research Methodology

In this context, five manufacturing companies have been examined on the impact of Order Entry Points; the scope did include manufacturing management and engineering management (product development in these companies has been embedded in the engineering department). The theory of modular design leading to a coherent approach to product architectures originates from earlier research (Bikker, 1992; van der Sterre, 1992). Logistic implications and a proposal for control have been discussed in Dekkers & Sopers (2001). The earlier research shows the successful implementation of the concept though it implies that companies have to adapt their operation's practices and systems. Action Research in all five case studies – with the findings in separate reports - revealed that a new organisational structure with upstream Order Entry Points would prove beneficial.

However, it remained unclear which impact these Order Entry Points would have on control of engineering to meet customer demands and therefore this has been examined separately (this was one of the remaining research topics mentioned by Bikker & Dekkers [1994]). Nonetheless, engineering management cannot be separated from the 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 will analyse the issues related to the implementation in engineering management. The added value is the disclosure of a field not well-studied in literature.

The paper will start with a description of the processes within industrial companies, directed at the engineering and manufacturing processes. Section 2 links these processes to the Order Entry Points mainly based on the previous publications, which relate closely to other literature in this field; however, the benefit is the distinction of Order Entry Points for both production and engineering processes. For some readers these theories might prove common ground. Section 3 introduces the theoretical framework for engineering management by the link to the Order Entry Points. This section presents the five case studies conducted within this framework and reports on the findings of the research into engineering management. Section 4 concludes the paper and displays the recommendations following from this research, which enables companies to cope with the contemporary challenges for performance and strategy more effectively caused by the trends of increasing variety and customisation.

2. ORDER ENTRY POINTS

That the current trend of customisation affects the control of operations within industrial companies leaves no doubt. Lampel & Mintzberg (1996) demonstrate the change of the demand by clients and the penetration of this demand into the organisation. Child et al. (1991) note that in some cases, companies attribute as much as 30% of their costs to product variety, while these variations account for as little as 3% of sales. Wüpping (1998) notes that especially during difficult times companies tend to accept any customer requirement not to leave any space to competitors. This illustrates the impact of the strategic choice on the performance of companies with the continuum of strategic choice ranging from pure standardisation to pure customisation. Pure standardisation leaves no room for differentiation, segmented standardisation may provide different distribution services or channels to different customer segments, customised standardisation encompasses final assembly of modules according to specific customer requirements, tailored customisation includes customer-specific components and modules in the final assembly, and pure customisation covers all specific process to meet unique customer requirements. According to Lampel & Mintzberg (1996) these five types, especially the trend for standardised customisation, effects the way anyone looks at organisations and the control of the primary process.

[Insert Figure 1 about here]

Figure 1 describes the design processes, engineering processes and manufacturing processes; it distinguishes two main processes: the product information flow and the material flow. During the product information flow, client requirements transform into specifications and instructions for manufacturing. The material flow concerns the manufacturing of parts and the assembly of the final products from parts and purchased parts. The *Sales Process* of this model translates the client's requirements into specifications for engineering. The sales process is not only performed by the sales force but might involve other personnel, such as sales engineers, project engineers, engineers and technical buyers from the customer. The *Engineering Process* transforms the specifications from the sales process into standards and information for production, i.e., drawings, assembly instructions, etc. Before using these standards and information, the manufacturing engineering function adds production instructions for the actual production process. The

Manufacturing Process, including purchasing materials and parts, converts these materials and parts into products ready for distribution and delivery.

When the delivery times for a company decrease, the turnaround for logistic control arrives if the lead-time for delivery of specific orders approaches or becomes shorter then the throughput time for engineering and manufacturing. Especially in the case that clients require specials or specific requirements they have a few options for the product information flow and the material flow. For the product information flow, companies might reduce further on lead-time through:

- introducing new methods of working;
- concurrent and simultaneous engineering;
- reuse of constructions.

The introduction of new methods, concurrent and simultaneous engineering will not always have the desired effect. The options will reduce delivery time but they approach the specific client requirements from a project-oriented point of view (Dekkers, 1997). The reuse of constructions makes it possible to apply already developed components and assemblies for a new client order.

2.1 Order Entry Points

[Insert Figure 2 about here]

Within the material flow companies have only as an option to manufacture on stock, located on an appropriate point within the manufacturing process. This point of stock is called the Custom Order Entry Point. The point where an order enters the material flow, the Custom Order Entry Point (COEP), determines which specific activities have to be undertaken after the start of a custom order (Figure 2); please note that the points of stock have been omitted from the figure. Although instructions have to be prepared by manufacturing engineering for any of the subprocesses of production, the effect of the various entry points is different. On the extreme side where final products are kept at stock, the effect of an order restricts itself to the distribution of the finished product (COEP-1 equals Ship-to-Stock). The second COEP indicates that shipment processes have to be included into the specific activities (Make-to-Stock). When assembly activities belong to the execution of an order the COEP positions itself at point 3 (Assemble-to-Order) and in the case of manufacturing of parts at point 4 (Make-to-Order). Engineering-on-order will mostly result in purchasing specific parts and materials for that order and enters the manufacturing process at point 5 (Buy-to-Order). Downstream of the COEP no stocks should be available for sales and that the logistic decisions mostly affect the risks and opportunities for accepting orders. Olhager (2003) discusses the pros and cons for shifting the Order Entry Point forwards and backwards. Upstream decisions direct themselves at the risks coming along with investing in stocks. The COEP represents in most cases the latest stock point in the logistic chain; from this point on client's orders have to be delivered. Before this entry point, the forecasts of the orders guides the planning of manufacturing activities; for example, the production planning might be based on MRP-II (Andries & Gelders, 1995, p.36; de Haan et al., 2001, p. 107). After this entry point, the emphasis on control of manufacturing shifts to lead-time and flexibility since specific customer requirements have to be met (the agility of the supply chain).

Thus, the dilemma for the engineering process remains how to reduce costs by reuse of designs and at the same time reduce total lead-time while clients have specific requirements. Similarly, to the material flow, the product information flow has a point where a custom order enters the process. The product information flow generates the related specifications and instructions for the manufacturing process. The position of the Order Specification Entry Point (OSEP) indicates the amount of engineering work before any order is specified for manufacturing and logistics. The more the design and configuration has been developed in advance, the less the amount of engineering work that remains to be done for processing a specific order. When the client accepts an order for an already defined product, the product information is then ready for manufacturing. In such a case, the order information is directly transferred to production engineering or shipment and distribution (OSEP-1 in Figure 2). Position 2 of the OSEP indicates that production engineering has to transform the standard information from engineering into information for manufacturing; the order does not require any specific engineering. Either Engineering-to-Order leads to adaptations of existing configurations (OSEP-3) or a total dedicated design (OSEP-4). The product architecture has a strong influence on the position of this point. Any change in requirements from clients that leads to a new design or similar effects, moves the position of the OSEP to point 4 with its lead-times. The points OSEP-1 and -2 indicate how successful a company is by reusing configurations.

2.2 Product Flexibility and the Order Entry Matrix

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

Figure 3). Different products and constructions may require different positions of these points in the Order Entry Matrix. When an OSEP for a certain product architecture allows acceleration of the order processing during the specification process, management has still freedom in positioning the COEP.

[Insert Figure 3 about here]

The choice of the COEP determines mostly the performance of manufacturing and losgistics. The decision for the COEP one derives from:

- the availability of the product specification for production;
- the permitted lead-time;
- the frequency of expected sales of individual modules.

The Order Entry Matrix reveals which measures to take for reducing the lead-time and increasing the productivity and flexibility. Moving the entry points downstream will reduce the lead-times and improve the reuse of product configurations.

When a company has different OSEP/COEP combinations that might be attributed to three reasons. Firstly, some product architectures and components require only assembly for a specific order while at the same time specific materials have to be purchased. Secondly, special requirements influence only part of the total design; this implies that some parts are not affected while other products or components need a redesign to meet customer demands. Finally, the whole range of products of a company can have different combinations; standard products have a different combination than products with much engineering work.

The pull from the market for dedicated variety as a result from customer demands should be regarded as given. The product flexibility can be illustrated by positioning each variant within the Order Entry Matrix. Before doing so, the product has to be broken down in components called modules. This product architecture follows the definition of modules as presented by Bikker & van der Heyden (1987). Weinbrenner & Ehrlenspiel (1993) have presented a similar breakdown in modules, sub-assemblies, etc. In Figure 4 we see different modules as part of the total product family. One will find basic modules in each product; client specifications do not influence the design of this type of module. Standard modules refer to modules from which different designs are available and which have to be used in each product. Examples of such a module might be the choice for a 110V or 230V power supply. Standard optional modules are features and additions that the client might choose from a short-list. When the client specification cannot be related to these modules, a special module might be created.

[Insert Figure 4 about here]

When applying the Order Entry Matrix, a product family can be configured consisting of assemblies and parts. The sales and engineering process should direct client requirements to standard modules, standard option modules and specials. By minimising the use of special modules, the dilemma of variants and variety will be met. Such a family of products configured in modules each serving an original function or sub-function provides one of the most promising answers to the dilemma. On this matter, Eekels (1993) has already pointed out that the relationship between client and supplier exists on the exchange of functions. Similarly, Meyer & Utterback (1993) describe the core capability as keystone for configuring products and product families. In that view, the underlying value of a product family is represented by the core capabilities of products and the value for the customer; both the core capability and the value resemble Eekels' description of function.

3. ENGINEERING AND ORDER ENTRY POINTS

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

3.1 Impact of Modular Design

The most effective way of managing the engineering process is by modularisation. This topic has been widely investigated but weakly linked to the Order Entry Points in that same literature. The OSEP indicates the type of work and the amount of work to be done for a customer order. For example, will only be possible if the product design consists of standard modules, basic modules and (sometimes) optional modules. The foremost effect of the Order Entry Matrix and the belonging modular design constitutes the different modus 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 engineering and manufacturing companies that produce on order (before the implementation of the Order Entry Matrix). The issues for the engineering processes and management have been listed in the last column of Table 1.

[Insert Table 1 about here]

The first four cases concerned both the engineering process and the manufacturing process; the integrated improvement of the primary process to meet shifting performance requirements stood at the heart of these studies. These four cases constitute industrial companies that produce small-series to medium-sized series of equipment for industrial use, mostly. Traditionally, engineering activities during the conversion from customer requirements to manufacturing instructions resulted in lengthy lead-times, reduced efficiency and difficult operational control. Although the specific solutions for the companies varied, they all embodied the introduction of Order Entry Points and modular design. The studies have resulted in improvement of the conflicting requirements of lead-time, product flexibility and productivity.

The fifth case study did focus on the engineering process. The company executed orders for the construction industry, mainly by producing equipment for plants. The company's competitive advantage was to deliver custom-made equipment, in contrast to the competitors that delivered modular designs. Additionally, the analysis of five projects revealed that the losses amounted up to 20% per project due to an excess of engineering hours. This excess could be avoided by a more standardised operating procedure for the design and engineering of the products (based on small increments, that way approaching tailored design), in a way moving towards OSEP-1. A computer program based on a standardised design and modular components has been developed to conduct the pre-design and initial stages of the engineering process. The proposal decreased the number of hours and decreased the lead-time. Because of the low number of projects and specific requirements it is not possible to assess the exact improvements; an estimate showed that the payback time, for the standardised design and the implementation, could be 1-1.5 years.

Additionally, the shift in the Order Entry Points implies a separation between the processing of customer orders and product development. Only in Case B this has not been implemented due to the nature of the products, and due to the assessment of the company that their basic design would not need any upgrades for a while. In the old situations the engineering of customer orders and product development were intertwined in the skills and capabilities of individual engineers. The working methods introduced by modular design entail the division of the engineering process in three separate processes: (a) the engineering of special modules, (b) the preparation of documentation for manufacturing in case of OSEP-3 and OSEP-2, and (c) the development of new product designs. Yet, the strict separation of these processes (and their control) has not been implemented in any of the engineering departments; neither were engineers purely allocated to products or product families.

Furthermore, the process for managing market demands becomes paramount. A modular product architecture improves the response to specific customer demands at the expense of product flexibility. Developing each product on its own offers the best flexibility to the market; however, it does not solve the problems related to productivity and lead-time. The architecture of the product limits the implementation of any customer requirement; hence, in a certain way the product architecture decreases the product flexibility. Then it becomes more important to incorporate a well-defined set of requirements into the basic design.

Requirements outside the scope of the requirements should be treated as specials; processes should be in place to avoid overdraft on these types of projects (e.g. easier to sell for sales representatives but more costly to make). Although recognised as key point of strategy, none of the companies, except A, did actively control the tuning between sales and engineering on this point.

That brings us to the issues of integration between sales, engineering, manufacturing and logistics. Since these companies produce small series to medium-sized series and often incorporate engineering efforts in orders, the implementation of the Order Entry Points covers mostly the logistic issues. That leaves the amalgamation of sales, engineering and manufacturing as remaining issue. From Table 1 it appears that in only one case a product configuration system has been developed for assisting sales representatives while in the other cases the integration focuses more on standard procedures. Case C has also the largest series produced per year, may be the reason why such becomes feasible. In the other four cases, the companies do not see any need to go beyond the standardised working methods.

3.3 Discussion of Findings

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

This resistance comes along with the disconnection of operations (processing customer orders within the bandwidth of the modular design) and product development in engineering. One group should concentrate on the processing of orders and one on product development. The implementation of this working method did not properly take place in any of the companies, although Gulati & Eppinger (1996) indicate the close relationship between product configuration and organisational structure. The relative size of the engineering departments in the companies investigated and the specific knowledge of engineers make it more difficult to approach engineering management similarly as operations management.

In addition, the management of customers' requirements calls for an early detection of shifts and trends. Shifting trends and demands should lead to decision-making on optional modules, basic modules, conversion from special modules to optional modules and redesign of the product architecture (upgrade or new design). A loop to do so would suffice; this would act as a feedforward before the order processing to avoid an inflow of too many orders as custom design. Additionally, it would be necessary to include a detection of trends in customer orders to anticipate on future demands. This detection of shifts and the active management of the engineering process would also require the design of subsequent product families and platforms. Accumulation of customer demands and feedback from the routine engineering process and the manufacturing process might result in the need for developing new product families or platforms. Especially, the low level of cooperation between sales, engineering and manufacturing on this point can be seen as an 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 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 because by connecting different strands of research.

REFERENCES

Andries, B. and Gelders, L., Time-based manufacturing logistics. *Logistics Information Management*, 1995, 8(3), 30-36.

Bikker, H., Technisch management van produktwijzigingen, Deel 1: Produktwijzigingen aan de lopende band. *de Constructeur*, 1992, (4), 22-30.

Bikker, H. and Dekkers, R., The Order Entry Matrix: Keystone for Productivity of Design and Manufacturing, in *2nd International Conference Product Development Management on New Approaches to Development and Engineering*, 1994, pp. 44-58.

Bikker, H. and Heyden, W. v. d., Systematic Product Breakdown as a major tool for productivity improvement. *International Journal of Production Research*, 1987, 25(11), 1635-1644.

Child, P., Diederichs, R., Sanders, F.-H. and Wisnioswki, S., SMR Forum: The Management of Complexity. *Sloan Management Review*, 1991, 33(1), 73-80.

Christopher, M., The Agile Supply Chain. *Industrial Marketing Management*, 2000, 29(1), 37-44.

Christopher, M. and Towill, D. R., Supply chain migration from lean and functional to agile and customised. *Supply Chain Management*, 2000, 5(4), 206-213.

Croxton, K. L., Garcia-Dastugue, S. J., Lambert, D. M. and Rogers, D. S., The Supply Chain Management Processes. *The International Journal of Logistics Management*, 2001, 12(2), 13-36.

Dekkers, R., Concurrent Engineering and Project Management as Tools for Product Development, in *4th International Product Development Management Conference*, 1997, pp. 241-250.

Dekkers, R., Strategic Capacity Management: Balancing Technological Demands and Performance Criteria. *Journal of Materials Processing Technology*, 2003, 139(1-3), 385-393.

Dekkers, R., *(R)Evolution, Organizations and the Dynamics of the Environment*, 2005 (Springer: New York).

Dekkers, R. and Sopers, F. P. M., Production Control and the Order Entry Point, in *16th International Conference on Production Research*, 2001 [CD-ROM].

Donk, D. P. v., Make to stock or make to order: The decoupling point in the food processing industries. *International Journal of Production Economics*, 2001, 69(3), 297-306.

Eekels, J., Ontwerpen en het realiseren van waarden. *de Ingenieur*, 1993, (6), 44-47.

Furukawa, Y., Paradigms for Future Manufacturing Systems (keynote), in *9th Annual Conference CIM Europe*, Amsterdam, 1993.

Gulati, R. K. and Eppinger, S. D., The Coupling of Product Architecture and Organizational Structure Decisions. Working Paper 3906, MIT Sloan School of Management, 1996.

Giesberts, P. M. J. and Tang, L. v. d., Dynamics of the customer order decoupling point: impact on information systems for production control. *Production Planning & Control*, 1992, 3(3), 300-313.

Graves, S. C. and Willems, S. P., Optimizing Strategic Safety Stock Placement in Supply Chains. *Manufacturing & Service Operations Management*, 2000, 2(1), 68-83.

Haan, J. d., Yamamoto, M. and Lovink, G., Production planning in Japan: Rediscovering lost experiences or new insights? *International Journal of Production Economics*, 2001, 71(1-3), 101-109.

Henderson, R. and Clark, K., Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly*, 1990, 35(1), 9-30.

Hoekstra, S. and Romme, J. H. J. M., *Op weg naar integrale logistieke structuren*, 1985 (Kluwer/NIVE: Deventer).

Lampel, J. and Mintzberg, H., Customizing Customization. *Sloan Management Review*, 1996, 38(1), 21-30.

Lee, W. B. and Lau, H. C. W., Factory on demand: the shaping of an agile production network. *International Journal of Agile Management Systems*, 1999, 1(2), 83-87.

Mason-Jones, R., Naylor, B. and Towill, D. R., Engineering the leagile supply chain. *International Journal of Agile Management Systems*, 2000, 2(1), 54-61.

Meyer, M. H. and Utterback, J. M., The Product Family and the Dynamics of Core Capability. *Sloan Management Review*, 1993, 34(3), 29-47.

Mikkola, J. H. and Skjøtt-Larsen, T., Supply-chain integration: implications for mass customization and postponement strategies. *Production Planning & Control*, 2004, 15(4), 352-361.

Naylor, J. B., Naim, M. M. and Berry, D., Leagility: Integrating the lean and agility manufacturing paradigms in the total supply chain. *International Journal of Production Economics*, 1999, 62(1-2), 107-118.

Olhager, J., Strategic positioning of the order penetration point. *International Journal of Production Economics*, 2003, 85(3), 319-329.

Riedel, J. and Pawar, K. S., The strategic choice of simultaneous versus sequential engineering for the introduction of new products. *International Journal of Technology Management*, 1998, 6(3/4), 321-334.

Rudberg, M. and Wikner, J., Mass customization in terms of the customer order decoupling point. *Production Planning & Control*, 2004, 15(4), 445-458.

Sabri, E. H. and Beamon, B. M., A Multi-Objective Approach to Simultaneous Strategic and Operational Planning in Supply Chain Design. *Omega*, 2000, 28(5), 581-598.

Sanchez, R., Creating Modular Platforms for Strategic Flexibility. *Design Management Review*, 2004, (Winter), 58-67.

Schuh, G., Schwenk, U. and Speth, C., Komplexitätsmanagement im St. Galler Management-Konzept. *io Management*, 1998, (3), 78-85.

Sharman, G., The rediscovery of logistics. *Harvard Business Review*, 1984, 62(5), 71-80.

Simpson, T. W., Maier, J. R. A. and Mistree, F., Product platform design: method and application. *Research in Engineering Design*, 2001, 13(1), 2-22.

Spring, M. and Dalrymple, J. F., Product customisation and manufacturing strategy. *International Journal of Operations & Production Management*, 2000, 20(4), 441-467.

Sterre, A. H. J. v. d., Technisch management van produktwijzigingen, Deel 2: Produktwijziging en logistiek. *de Constructeur*, 1992, (5), 50-54.

Stone, R. B., Wood, K. L. and Crawford, R. H., A heuristic method for identifying modules for product architectures. *Design Studies*, 2000, 21(1), 5-31.

Vlist, P. v. d., Hoppenbrouwers, J. J. E. M. and Hegge, H. M. H., Extending the enterprise through multi-level supply control. *International Journal of Production Economics*, 1997, 53(1), 35-42.

Vries, G. d., Bertrand, J. W. M. and Vissers, J. M. H., Design requirements for health care production control systems. *Production Planning & Control*, 1999, 10(6), 559-569.

Wanke, P. F. and Zinn, W., Strategic logistics decision making. *International Journal of Physical Distribution & Logistics Management*, 2004, 34(6), 466-478.

Weinbrenner, V. and Ehrlenspiel, K., Produktlogik, Ein Hilfsmittel zur Automatisierung von Varianten- und Anpassungskonstruktionen, in *International Conference on Engineering Design*, 1993, pp. 1594-1601.

Wemmerlöv, U., Assemble-to-Order Manufacturing: Implications for Materials Management. *Journal of Operations Management*, 1984, 4(4), 347-368.

Wüpping, J., Logistikgerechte Produktstrukturen bei marktorientierter Variantenvielfalt,. *io Management*, 1998, (1/2), 76-81.

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

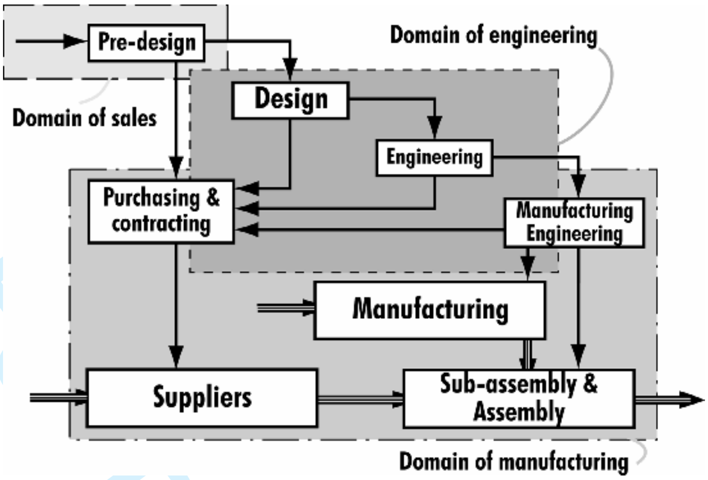

Figure 1: *Simplified, generic total primary process. The total primary process consists of two flows: (1) the material and logistic flow in the domain of manufacturing and (2) the information flow, product and process data, related to product development and engineering..*

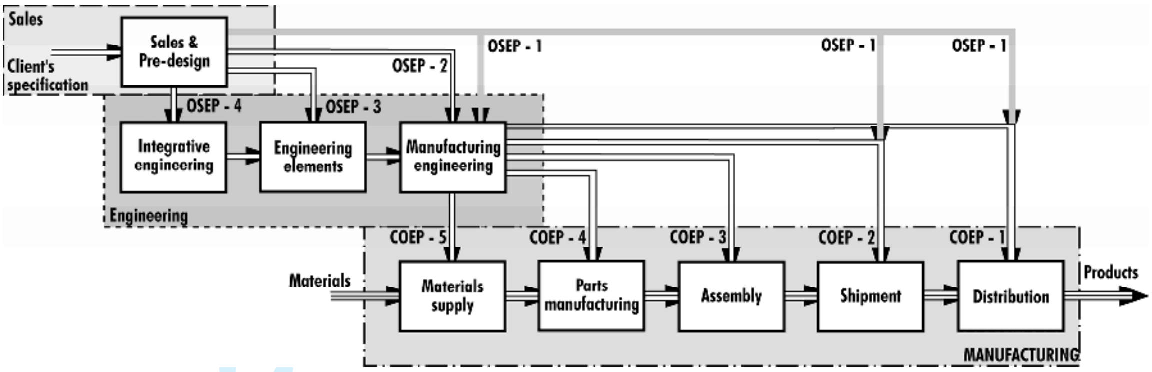

Figure 2: Position of the Order Entry Points in the primary process of design, engineering, manufacturing and logistics. To simplify the figure points of stock have been omitted. OSEP-1 (Order Specification Entry Point) indicates that customer requirements are directly transferred into production instructions,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

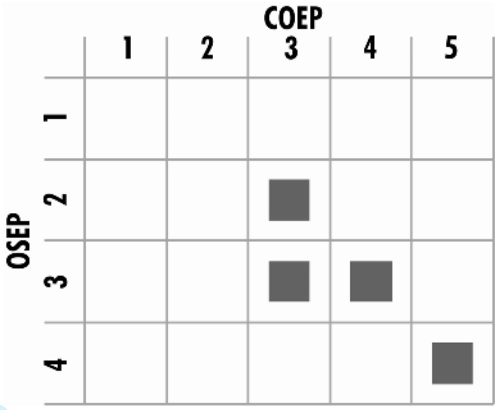

Figure 3: Order Entry Matrix. The position in this matrix indicates the efforts required to fulfil an order. Products might consist of different components with different combinations of the Order Entry Points.

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).