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USING MULTIPLE MODULAR STRUCTURES IN DELIVERING COMPLEX PRODUCTS

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Abstract

This paper presents a new concept for structuring a product in relation to the business paradigm by analysing order-delivery processes of the company. The aim of the paper is to illustrate the dependencies between *product internal characteristics* and the *order-delivery process*. The idea is to acknowledge multiple modular structures in a one product and to address the challenge it imposes to the operative efficiency of the company. The focus is on partly configurable products where this phenomenon is easily visible. The main finding is that the use of multiple modular structures with matching combination of operative modes improves efficiency in delivering complex products.

Keywords: Product structuring, modularity, configurable design processes, partly configurable product

Introduction

The motivation for this study was to find ways of improving R&D efficiency in delivering complex products. The work effort needed per delivery was identified as the key driver for profitable operations and the target of reducing work effort was planned to achieve by means of design reuse.

Victor et al. [1] presented the mass customisation paradigm as solution for companies that were struggling with low profitability and efficiency. The mass customisation would enable the company to produce efficiently products yet meeting individual customer needs. It consists of benefit from economies of scale - the reuse of key parts increases the volumes and reduces the cost of key parts. This study draws on the Mass Customisation Paradigm by studying products in shipbuilding and in telecommunication industry where similarities were found. The products are complex, having multiple subsystems and sub subsystems with high level of interdependencies. The products are developed to meet customer and internal stakeholder needs very closely. In addition, both products are developed using one-of-a-kind process. The approach for the study is illustrated in figure 1.

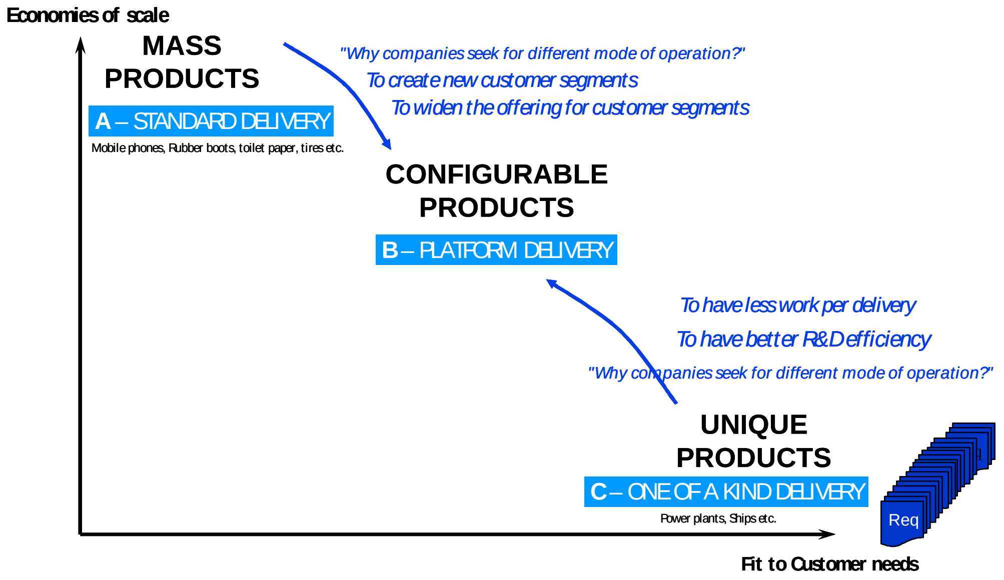

Figure 1. The positioning of mass products and one of kind products. The vertical scale is the amount of products manufactured and the horizontal scale the product capability to meet individual customer needs.

The figure 1 is result of Design for Configuration research [2] carried out during 1997-1999 in Finnish industry. The configurable products are positioned in between because they enable benefit from economies of scale and meet the customer needs better than mass products.

Configuration was defined as task done during the order-delivery process when selecting from multiple options to modify the product to meet customer needs. This definition rules out any design work to be done in the order-delivery process because it was found as best practice in companies making profit with configurable products. The design was carried out in separate development process beforehand.

The state of the art was to utilise sales configurators enabling definition of each product individual without deep knowledge of the product and technologies used. The design rules were captured, analysed and formulated as rules or constraints for sales configurator. The sales person was then able to use the configuration knowledge for fast, efficient and reliable product configuration task.

Theory base

This research is based on the Mass Customisation Paradigm [1] and the Design for Configuration research carried out during 1997-1999 [2] in Finnish industry. The starting point has been the design process proposed by the German school of Design Science [3] and the Theory of technical systems [4]. The System Engineering [5] and the V-model [6] approach has had major impact during the study. The process modelling and modelling of operative mode draws on the business process re-engineering and principles of process management [7, 8].

Research methods

The research methods used are case study and ethnographic research. The observations take place in telecommunications industry during 1999-2006, in shipbuilding industry 2004-2006 and in Finnish SME´s during 1997-1999.

Observations in the telecommunication industry

The first observation is that the order-delivery process differs from one-of-a-kind delivery from configurable delivery. This is evident in the manner how customer needs are handled; in one-of-a-kind delivery, they are input to the design as in configurable delivery they are used in choosing close enough matching function and part.

Another significant difference in order-delivery process exists between configurable delivery and mass products; the focus in configurable delivery is on choosing between different parts whereas in mass product the focus is choosing between different products. As result of the differences, the configurable product and mass product require no engineering in order-delivery process thus reducing the work effort needed per delivery. The one-of-a-kind delivery requires always some unique design to have functions and parts to meet customer requirements. It is important to notice that by default, the design done is not reusable and the design unique -task differs from design for reuse –task. The first task was to solve the unique situation with unique needs in best possible way, usually with unique solution. The target in design for reuse is to solve unique situation with standard solution.

The next observation was that delivery specific design was done in projecting business and in mass customization business yet the objective was to maximize the amount of design reuse. Because the reporting mechanisms did not support measuring design reuse, it was very laborious to analyse the amount of delivery specific design and amount of reusable design. During the analysis, a classification for parts was proposed to enhance measuring design reuse. Further study indicated that each delivery contained some standard parts, some configurable parts and some unique parts. The observations and logic is visualised in figure 2.

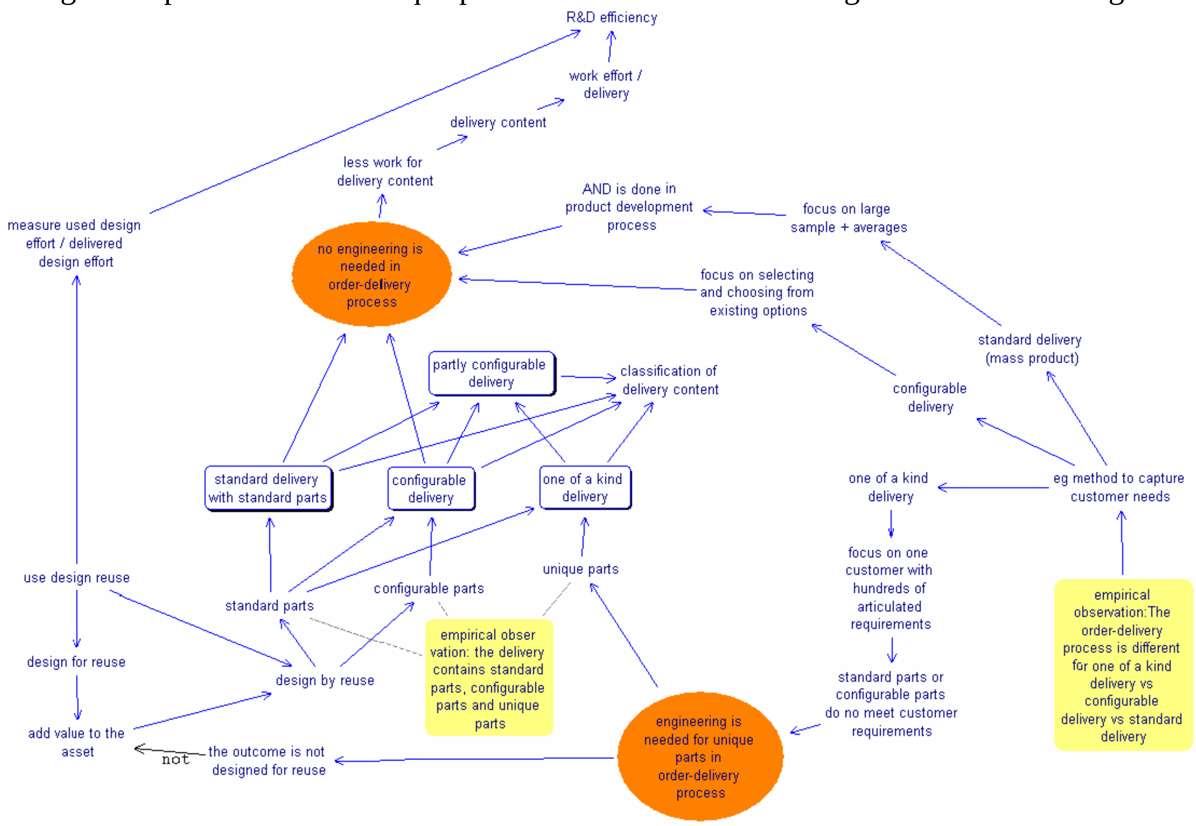

Figure 2. The observations and logic in analysis. The observation is on lower right-hand corner and the differences are highlighted with orange bubbles. The classification is presented with rounded rectangles.

Generalisation

The first hypothesis is that a division based on the design type needed per delivery can be found inside a product. This division is called product internal characteristics. With this thinking, the product consists of four categories of elements: First: *Standard parts* with no delivery specific design, second: Some *unique parts designed just for that particular delivery*, third: The *configurable parts*. The fourth category is combination of other categories above. The share of each category varies from product to product reflecting the amount of design needed per delivery. The classification is illustrated in figure 3.

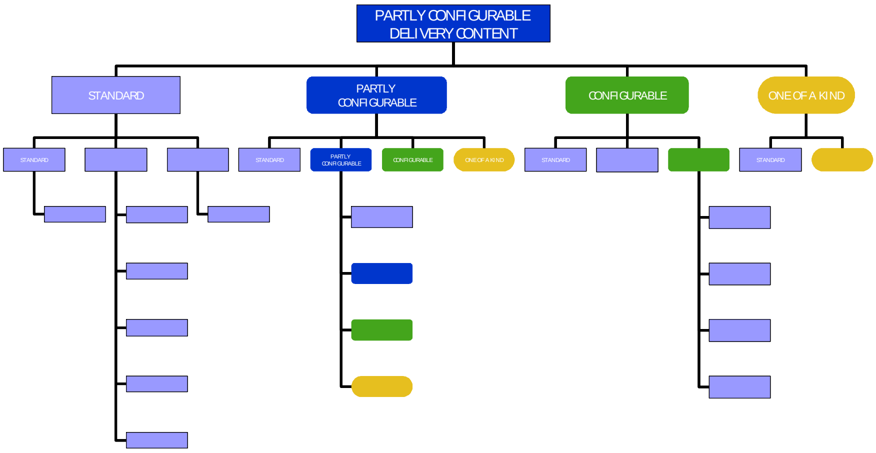

Figure 3. The classification of product internal characteristics. In this example the product type is partly configurable and consists of standard parts, partly configurable parts, configurable parts and one-of-a-kind parts.

Standard part is product element that is designed to be reused in many products as such. The design takes place in development process, not in order-delivery process. Even the element is standard part in can require some integration and verification effort to be fully functional in the whole product.

Configurable part can contain standard parts and configurable parts. Depending on the configuration method, the variability can be achieved by using standardisation (sectional modularity, bus modularity), interchangeable parts and parameter-based modularity.

One-of-a-kind part is designed for one particular instance and the objective is not to achieve a standard part as result. One-of-a-kind part can contain standard parts and unique parts.

Partly configurable part can contain standard parts, configurable parts, one-of-a-kind parts and partly configurable parts. This type is combination of types defined above and it is needed to be able to model and analyse the design process and delivery process of a product. When the product is modelled, using these guidelines, the design reuse is measurable and it can be used to improve efficiency of design by reuse, for example.

The second hypothesis is that the product development process and order-delivery process have different objectives and logic resulting in different types of deliveries. General steps in new product development are as follows: Specify needs - Specify architecture - Specify component - Manufacture component - Integrate components - Verify product - Validate product.

The step “Use” is added between manufacturing and integration because not all parts are created from scratch for the specific delivery as observed previously. With standard deliveries and configurable deliveries the order delivery-process begins from manufacturing or Use and ends up with validation. In the illustration steps are from left to right and the each row represents process modules needed for each content type. In general the assumption is that each process module differs from other process modules because they are for different content type or process step. See figure 4.

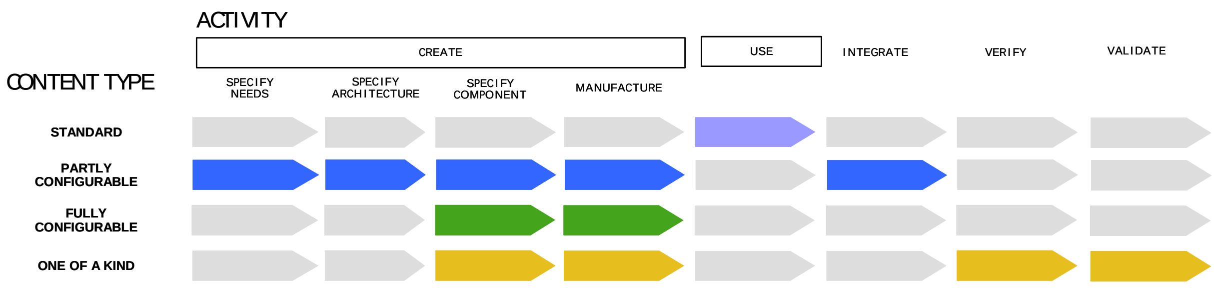

Figure 4. The process chart for different delivery types. The picture indicates process modules needed for design and delivery of partly configurable product.

The case example is from telecommunication industry and the delivery type is partly configurable product. The product development process starts with needs specification work and continues on the same row to architecture specification. At this point there is enough knowledge to continue with parallel processes; component specification for partly configurable, configurable and one-of-a-kind components. The manufacturing follows the same content types and in this case only standard components are reused – step use in the figure 4.

The integration step follows the delivery type and in this case, the verification and validation is done in similar manner as one-of-a-kind product, therefore the steps are according that content type. The figure 4 shows the usage of different process modules and in figure 3 the structure and type of delivery content can be seen. Now there exist structure and model for delivery content type and delivery mode. The optimisation task is to align content type and mode. The logic is described in figure 5.

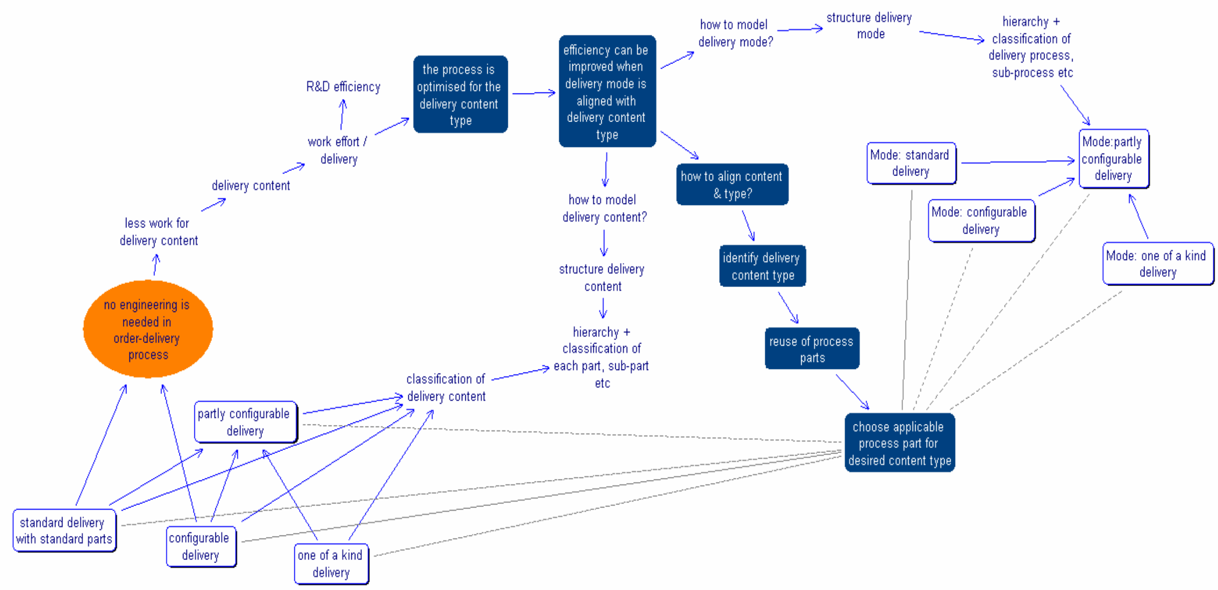

Figure 5. Aligning content type and mode. The aim is to choose applicable process part for desired content type.

Case Marine industry

Change in the tradition of shipbuilding

The traditional way of building ships regards the building of the hull as the most important task to be done in the shipyard. The fitting of the interior was seen far less important. However, this approach is not feasible when building cruise ships and passenger ferries. The amount of investments in interior and equipment is far bigger than the investment of the hull. There is neither business logic nor technical reasons anymore in building the hull first and constructing the whole ship within traditional hull building constraints.

According the visionary ideas presented in research and development projects with European shipyards, the shipbuilding should become more assembly work than actual building and manufacturing. One slogan presented here is “from ship to shop”. The idea here is that the actual manufacturing work on the deck of a ship is transferred to workshop on the land. The motivation to this is a fact that the efficiency of the work done in the workshops is much higher than the efficiency on the board of a ship. The ultimate goal is to achieve level where manufacturing of the parts and prefabricated elements is made industrial manner and only assembly work is done at the shipyard.

These trends are the reasons for a change that has already started for example in the Finnish marine industry. The technical challenges here can be solved with knowledge and skills available. The most crucial problems to overcome are in the area of product structuring. The industrialization of part manufacturing requires a moderate high level of standardization. How this could be achieved?

Encapsulating the variety

Building of cargo ships in Korea has achieved a very high efficiency level by standardizing work. The ships made there are very much alike. The problem is that there is and probably never will be no “standard luxury cruise vessel”. In the cruise ships business it is a value in itself that every ship is an individual. The more leisure time travellers are among the ships passengers, the more important are the ship specific solutions also in the passenger ferry business. This imposes strong drive for projecting one-of-a-kind products.

Thus, there is a need of building different ships by using the same parts. The obvious solution is modularizing the ship and encapsulating the variance inside the modules. If all the variance in ship delivery project would come from the customer, this would probably be adequate solution.

The effect of subcontractor network

Very few – of none - shipyards in the world build the whole ship by themselves. Within Finnish marine industry, the subcontractor network is particularly wide and important. The transferring the work from the ship to the workshops on the land will increase the possibilities to divide the work to subcontracting network. However, the ship building business is very seasonal. When the order books are full, there is plenty of work available, but when there are no ship orders, the contractors have to find something else to do. This leads to situation that the contractors vary from delivery to delivery, because the industry cannot afford to pay for just keeping the resources available.

This is no problem as long as the alternative subcontractors are at the same skill and ability level. However, in fact they are not. Some subcontractors are able to make turnkey deliveries including the design, part manufacturing, assembly and testing. There are even a handful of companies capable of making new product development as a turnkey delivery. On the other hand, many companies are specialized only in making assemblies on board of the ship. Due this difference between the abilities and skills, one product structure solution is not optimal for everybody. For example, there is no point for small contractor with skilled workers and poor (or non-existent) workshop facilities to start building prefabricated modules.

This leads to situation that there are no two ships alike when observing the building process. Moreover, there is no two ships with similar product structure when we consider the "as delivered" -structures. This makes modularization extremely difficult. Following problems are common: A module is used only once and never repeated, modules are very small – maybe no more than an assembly of couple of parts, proposed modular structures are not chosen in the design phase but new design is made instead. This leads to situation, that although there is modularity in the product, it will not give any financial reward!

Four standard delivery processes

The possibilities to standardize the product enough to have the modularisation effective are ruined by the variation of the delivery process. Consequently, the delivery processes should be handled some way. The empirical research revealed that there seems to be four ways how the deliver is done. The processes types are following:

1. "Shipyard coordinated project delivery": in this type, the product structure division is open. Any level of skill will do among the subcontractors, because the tasks can be made to suit. Due to the variation, there is no systematic re-use.

2. "Ship consisting of turn-key deliveries": in this type, a contractor (group) makes one area or system. The contractors must have the ability to deliver turnkey solutions. They make turn-key-solution compatible to each other, the interfaces and for example, pipeline routings are to be standardized. This standardization of interfaces is re-used and this makes possible the re-use of turnkey solutions.

3. “Modular ship delivery”: in this type, the ship is made from modules. This approach should be utilized from the very start of negotiations with customer to make sure that modules available could be used in the ship. If ship can be sold as a modular product, this enables a lot of reuse

4. “Extended enterprise model”: in this type, the ship is completed by network of companies. Sections of the ship are given to network member, who carry out the development work and handles delivering. Reuse is essential part of this way of working.

Different parts of a same ship delivery can be done with different delivery process type. This requires good coordination and not all combinations are possible. Important is however that selected process is used from the very start to the end.

Correlation to design theories

As the research continued, a comparison between the proposed delivery processes and the design processes presented in the research community was done. The result was very promising. For every delivery process found, equivalent design process can be found from the area of Design Science.

In the Shipyard coordinated project delivery a normal systematic design process for example VDI2221 [4] can be used. The process models used in Finnish shipyards are compatible with VDI2221 process.

When constructing the ship of turnkey deliveries, the importance of general architecture and the definition of interfaces will be stressed. The optimal design process is so called Systems Engineering, which follows the V-model [5]. Here the system and its architecture are designed first.

When the ship is build up from modules and idea is to use the same set of modules from delivery to delivery, we are very near to the idea of configurable products [9]. In this design process, no new design is made, but only selection of modules and integration design.

The Extended Enterprise way of working requires the most advanced tools in product structuring. On the other hand, there must be adequate freedom for partners in EE to develop theirs section of the products, but also the coordination and holistic properties must be handled. There are proposition of design processes having these abilities. In this research The Dynamic Modularisation –paradigm [10,11] is used.

Identifying the design processes gives the guidelines for making the actual product structures. The theory proposed in this paper is the other starting point. Identifying the standard, configurable, partly configurable and one-of-a-kind parts is tool for starting analyze of the current product structure. The managing of multiple product structures requires extra effort. However there is a vide variety of standardization and modularisation projects made earlier in the Finnish marine industry. These show that rigid modular structures are not long lasting solution.

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Discussion

Research context

The well-managed variety of product internal characteristics and modes of operating are needed to be competitive in the marketplace. Our study gives direction how to improve operative efficiency in delivering complex products. If the product has multiple modular structures the company needs to have flexibility and modularity in corresponding operative practice e.g. order-delivery process. The area for further research is how companies manage to have variety of operative practices within one product delivery. The search for one type of modularity in complex products is over – neither the function-structure-based nor assembly-based modularity alone does give sufficient solution for operative challenges.

Product internal characteristics classification

The delivery content classification made the phenomenon visible and it can be articulated more properly. The observations reveal that in large and complex product deliveries multiple modular structures are used deliberately and accidentally. The third hypothesis is that multiple modular structures are actually beneficial in delivering complex products. In large products, there can be standard parts, configurable parts, unique parts, and each one needs different way of operating.

Design and Delivery process classification

The case studies indicate that standard products are ordered and delivered using different process compared with one-of-a-kind products. This aspect suggests that from company efficiency viewpoint there exists strong correlation between the product internal characteristics and how the product is ordered and delivered. The correlation has impact on the work effort used per delivery. Currently the work effort is not followed in detail level in the case companies because the design done per product and the delivery specific design of delivery process is not seen important for operative excellence.

Possible implications

The case studies also support the hypothesis that there is motivation for using multiple structures in one product. They originate from the product complexity and from the heterogeneous supplier network where one is not possible to operate similarly with all suppliers. The results indicate that operative efficiency can be improved by reducing the work effort used in defining practicalities the order-delivery process. This can be achieved by creating modular structure for the order-delivery process and by reusing relevant *process-modules*.

As result of this study there is need to insert partly configurable product into the framework presented in the beginning. The partly configurable products are situated almost at the same position as the one-of-a-kind products as they meet the customer requirements almost as well. On the vertical dimension, partly configurable products are not as high up as the mass customised products because the unique part in the product does not allow as big volumes as mass customised products.

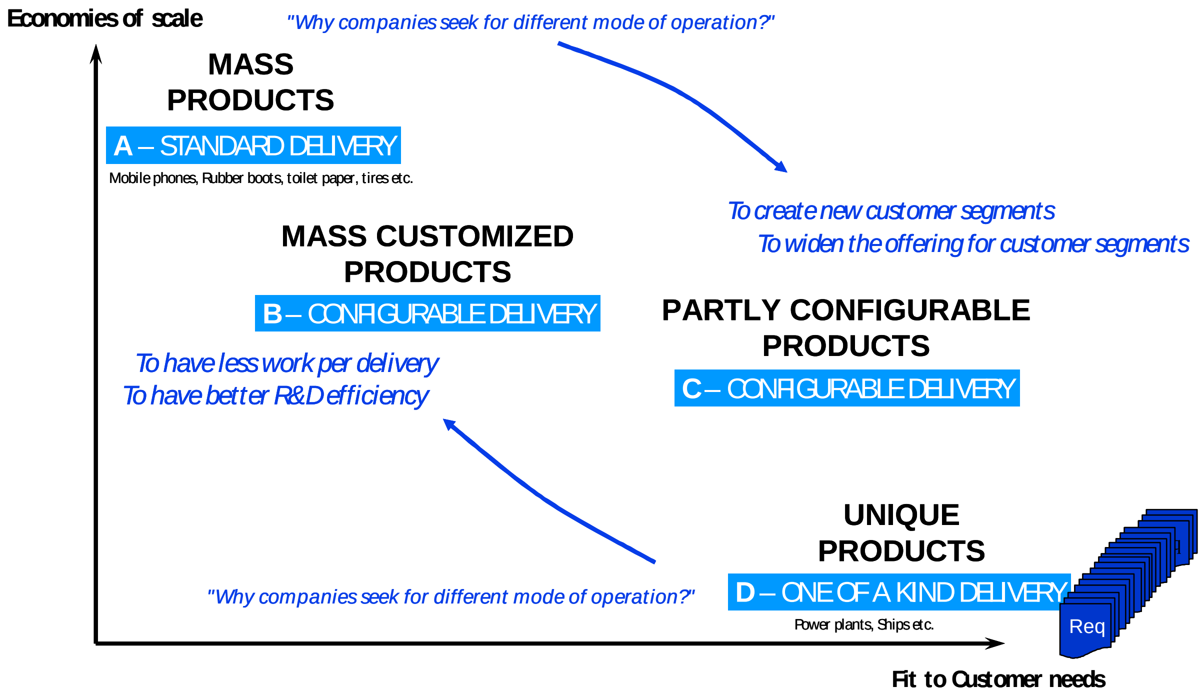

Figure 6. The revised framework and approach for developing products.

Future research

The classification of product internal characteristics offers possibility to study the different types of design task and imposed need to elaborate the different types of design process. It is also important to study how different tactics in the product modularisation interact due to the different natures of different technologies such as software and electronics.

The modelling of delivery content can provide new possibilities to plan and follow work effort per delivery and the amount of design reuse. It can also give new aspects for calculating efficiency of R&D.

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