INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 03 STOCKHOLM, AUGUST 19-21, 2003

MANAGING INDUSTRIAL PRODUCTS OF DIFFERENT DEVELOPMENTAL STAGES

Seppo Suistoranta

Abstract

A company creates variety to succeed on the market. This variety occurs in two dimensions: spatial and developmental. Spatial variety refers to the range of different products the company offers at a specific point of time, while developmental variety refers to the range of different developmental stages. The structure of spatial variety is generated in product development and it takes shape in a configurable product family. The sales process transforms variety into a variant mix by converting offers into factory orders, which are then entered to the factory's MPS (Master Production Schedule). Consequently, there are product variants of different developmental stages in the manufacturing pipeline. A specific maturation curve describes the time and rate of maturation for any variant. It corresponds to the readjustment time needed at the factory to recover from all the teething pains encountered in the meeting of product and process. The need for readjustment stems from the standard processes' inability to deal with the maturity aspect efficiently. To ensure a rapid solution of problems and short readjustment time, we recommend the use of a specialised process to give preferential treatment to those issues that disturb the operations of process pipeline.

Keywords: Industrial product design, product families, variety, workflow management

1. Introduction

Variety is one aspect of mass-customisation, whereby a company succeeds with a wide product variety. The customer-oriented approach also propagates variety, as the company constantly charts customers' needs and tends to be responsive. New market segments often assume specific product applications, which serve as a catalyst for new technologies. A determined product development process leads to platform extensions and new product derivatives. Today, a dynamic company will have a stream of products in the design and manufacturing pipeline. This stream is characterised by wide variety and numerous developmental stages.

Customers want ever shorter order-to-delivery cycles. To succeed in this, companies must develop efficient processes. The variant mix with different developmental stages raises the question of product maturity, i.e. its readiness for a given process. At the factory, it results in a readjustment time, during which standard processes lose their efficiency. To understand the reasons for this and find a remedy, we conducted an industrial case study at a company, which designs, manufactures and sells diesel-powered solutions for marine and power producing applications on the global market [1]. Our focus areas are the design and manufacturing processes at a product factory, which produces medium-speed diesel engines on made-to-order basis. The results of the study will be used for internal process development.

2. Product family

In this paper we use the word *product* in its most general sense, and *industrial product* as one that is designed for the business-to-business market. To cover a wide range of applications and performance requirements, a variety of products are needed. In many cases a product needs to be customised to meet the specific requirements of the customer's installation. Customised products add to the variety that the company offers and maintains.

To satisfy the variety requirement, a company can design and offer *a product family* to the market. By a product family we mean a set of products that are related. It provides a structured framework, in which to manage the whole spectrum of products. To signify that a product belongs to a specific product family we use the word *variant*, which is a product that is obtained by varying. In this context we also assume that the product family is configurable and every variant corresponds to a standard configuration.

2.1 Change

A product family is subject to a continuous change. This originates basically from time-based competition, which forces companies to shorten development cycles. Usually changes are intended to improve a product's functionality or manufacturability. These changes apply to the entire product family or to specific variants and they are implemented according to a planned program. Sometimes there are non-conformities or design faults, which require corrective actions. These lead to design changes, which must be implemented promptly.

There are two essential components that characterise the change of a product family: *rate* and *type*. Rate indicates the frequency of change and type the degree of change. The type of change can be additive or serial. A change is additive when existing variants are augmented by one or more new designs. A serial change is, in fact, a replacement, i.e. it replaces the earlier variant and the variety remains the same, [2].

2.2 Developmental stages

The predetermined change program together with the incidental changes lead to a high rate of change, which manifests itself in different *developmental stages* of product family and its members. This is depicted in Figure 1 (a) and (b).

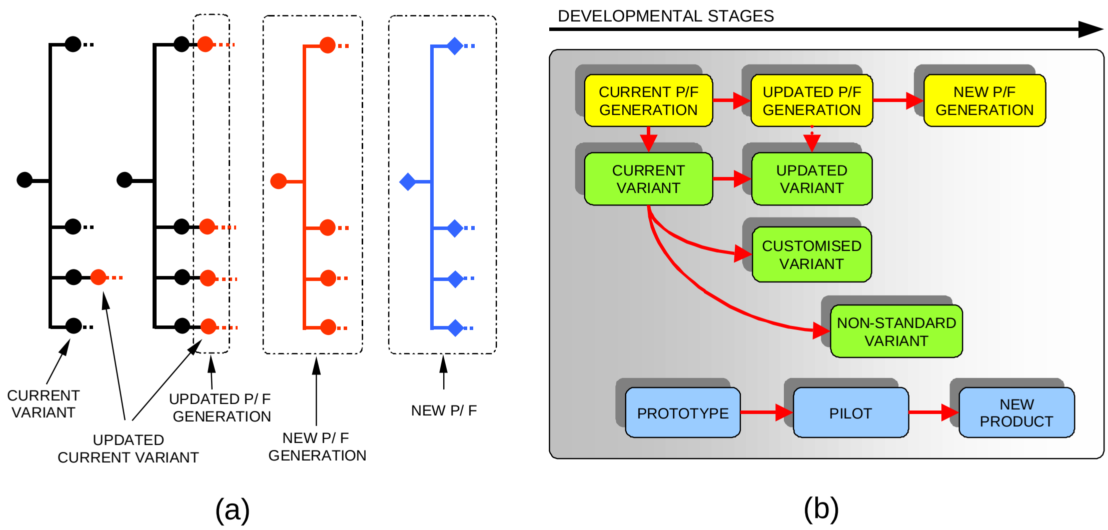

Figure 1. Model of product family evolution (a) and developmental stages (b)

A product family can be affiliated with a certain generation. Consequently, we refer to current product family generations and new product family generations. Usually a new generation is released when new technologies, functions or other significantly new features are introduced across all variants. It replaces the old generation during a transition period, which is determined based on market forecasts, pending customer orders, logistical issues, and the like. During this time there are actually two generations in the process pipeline.

Less radical changes are considered as an updating of the current product family. All variants are updated but on a less demanding schedule. The changes are of the serial type and mostly implemented based on the principle of interchangeability.

We also refer to single members of the product family as *standard variants*, because they are based on standard configurations. If the standard variant stems from the current product family generation, it is a current variant. The term *updated variant* has actually two meanings: it can simply refer to a member from an updated product family generation, but usually it refers to an individually updated current variant, Figure 1 (a). Such updatings are serial and typically interchangeable, but sometimes include new parts or subassemblies that are specific to that variant.

A *customised variant* is based on and designed for a customer order. Usually the customisations encompass small, installation-specific modifications, like the layout of interfaces, localised nameplates and units of measure. The physical changes are additive, even though functional properties are not changed.

A *non-standard variant* is based on, designed for and tested for a customer order. The changes to the standard variant may be considerable and result in modified operational properties. Usually a non-standard variant can be considered a one-of-a-kind product. On the other hand, the expected lifetime of an industrial product is long and the company must be able to offer regular service and spare parts deliveries through decades. Therefore we must add a non-standard variant to the variety.

A *new product* is based on a new product platform or an extension of an existing platform. Design gets its impetus from the basics, such as market research and feasibility study. A new product has two distinct developmental stages, which have a considerable influence on the manufacturing process. These stages are called the prototype stage and pilot product stage. A prototype is the first specimen of its kind. A pilot product is the first productional version subsequent to the prototype and is normally built for the first commercial order.

Structural domains

Introduction of any developmental stage requires an extensive amount of work, which encompasses engineering, calculations, drafting, testing and possibly logistical arrangements. All changes to the design can be charted within the different structural domains. Changes made in more abstract domains typically result in changes to the lower domains, which are then concretised in new or updated drawings, parts lists, material master data, etc.

We strive to apply the principles of reuse in new designs and updatings. Several indicators may be used to measure it, e.g. number of new drawings, number of new modules or number of new material codes. Figure 2 shows an estimated reuse percentage for structural domains at different developmental stages.

DEVELOPMENTAL STAGE	PROCESS DOMAIN	FUNCTION DOMAIN	ORGAN DOMAIN	COMPONENT DOMAIN
CURRENT P/F GENERATION	100	100	100	100
UPDATED P/F GENERATION	100	100	98	97
NEW P/F GENERATION	100	98	92	90
CUSTOMISED VARIANT	100	100	99	97
NON-STANDARD VARIANT	100	98	96	93
NEW PRODUCT	95	90	85	70

ESTIMATED REUSE-%:

REFERENCE =
CURRENT PRODUCT FAMILY GENERATION = 100 %

PERCENTAGE =

$$\frac{\text{\# OF REUSED OBJECTS}}{\text{\# OF OBJECTS}} \times 100$$

OBJECT =
DRAWINGS, MODULES, PARTS LISTS, MATERIAL CODES, ETC.

Figure 2. Estimated reuse percentage for structural domains at different developmental stages.

3. Maturity

By *maturity* we usually refer to product's position in its total life cycle. Its definition depends on viewpoint. The company considers maturity as a product's readiness for marketing and measures its commercial performance with various indicators, such as specific cost and revenue, warranty costs, market share, relation to competitors, etc. The customer estimates how good the product is for its business and compares it to competing references, thus forming an impression about the product's maturity.

Generally, maturity can be seen as product's readiness for some purpose. The purpose varies according to the product's prevailing life phase. In a company's process pipeline, the product must be ready for sales, ready for manufacturing, ready for dispatch and ready for use. Readiness can be estimated by comparing product's current state of embodiment to corresponding specification, which is expressed in configuration structures, completed drawings, purchased materials, planned routings, etc. If any drawing or engineering data is missing, we can say that the product is not ready for the prevailing process phase.

3.1 Maturation curve and pattern

Introduction of any developmental stage involves a *maturation curve*, which is measured from the release point to product's full maturity. The release point can be scheduled, but the time needed for full maturity depends on the amount of readjustment. Therefore the shape of the maturation curve varies, but it is related to the learning curve. Maturation time and curve has two expressions:

1. A specific variant being considered.
2. Whole product family being considered. In this case the maturation time covers all family members and maturation curve extends to a *maturation pattern*.

The amount of readjustment depends generally on the scale of change and its degree of difficulty, which can be expressed in the hours required for redesign, the number of updates made to the material master data, etc. In making readjustments, both the product and product-related documentation are subject to unintentional changes, which lead to unexpectedly revised drawings or unforeseeable material shortfalls. Work processes may need to be re-established. Readjustment reflects the product's maturity, and their ratio is inversely proportional.

The time needed for readjustments and, consequently, the product's maturity is also proportional to product's developmental stage. It is evident that a small update requires less readjustment compared to a new product family generation, non-standard variants or new products. Generally, we can say that changes made within more abstract domains lead to a low gradient curve.

The upper part of Figure 3 shows maturation curves and patterns for a product. The target level of maturity is denoted by *m*, signifying that the company considers the product fully mature. The scale in the maturity axis is relative. The individual maturation curves start at different levels, depending on the developmental stage. This model implies that the product is closer to full maturity, if the number of novelties is small.

4. Variety

There is no universal definition for variety. In our context it refers to a set of products, which are structured in such a way that is relevant to a company's business. This set of products constitutes a product family, in which every member can be configured and built from predefined structural elements or standard modules.

Product can be structured in many ways. Usually structuring factors refer to product's functions, performance or output. Based on this it is easy to compile a variety of products that cover a range of functions, performance and output, respectively.

We can use building blocks from different structural levels to create variety. In principle we could vary all BOM levels (bill-of-material). This would lead to a myriad of different variants and be extremely difficult to manage efficiently. Such variety would not really support company's processes, even if there would be some benefits from logistical point of view. A customised product can be regarded as an exception: it is based on standard modules that are modified at the BOM level.

4.1 Dimensions of variety

Martin [3] defines variety in two dimensions. The first one is related to the number of market segments, which in turn refers to the range of products that the company can offer at a certain point of time. This dimension is called *spatial variety*.

The other dimension is called *generational variety*, which is time-based. In the course of time a company releases new product generations, which later replace the old ones. Due to the transition period, there are always products of consecutive generations in the process pipeline being offered and manufactured parallelly. If we now add all developmental stages to this, we arrive at a more complicated time-based dimension that we call *developmental variety*. It covers the different developmental stages that we have in the process pipeline at a certain point of time. This infers that even if the range of products (spatial variety) remained the same, the developmental dimension may vary and add more variants to it.

The middle part of Figure 3 illustrates the dimensions of variety. A product family constitutes variants V_1–V_N. Spatial variety is therefore N. There are also generations G_1–G_k within the time frame, but at $t = t_s$ the developmental variety is 3. We arrive at this result by counting the variant (V_N, G_3), variant-specific updating for V_2 and a standard updating for V_1.

The word 'generational' refers to incremental change in the course of time, while 'developmental' emphasises a smoother, continual change. Therefore we suggest developmental variety as a generalisation of generational variety. In more abstract terms, we state that spatial and developmental components of variety form a space, where all individual product variants are defined.

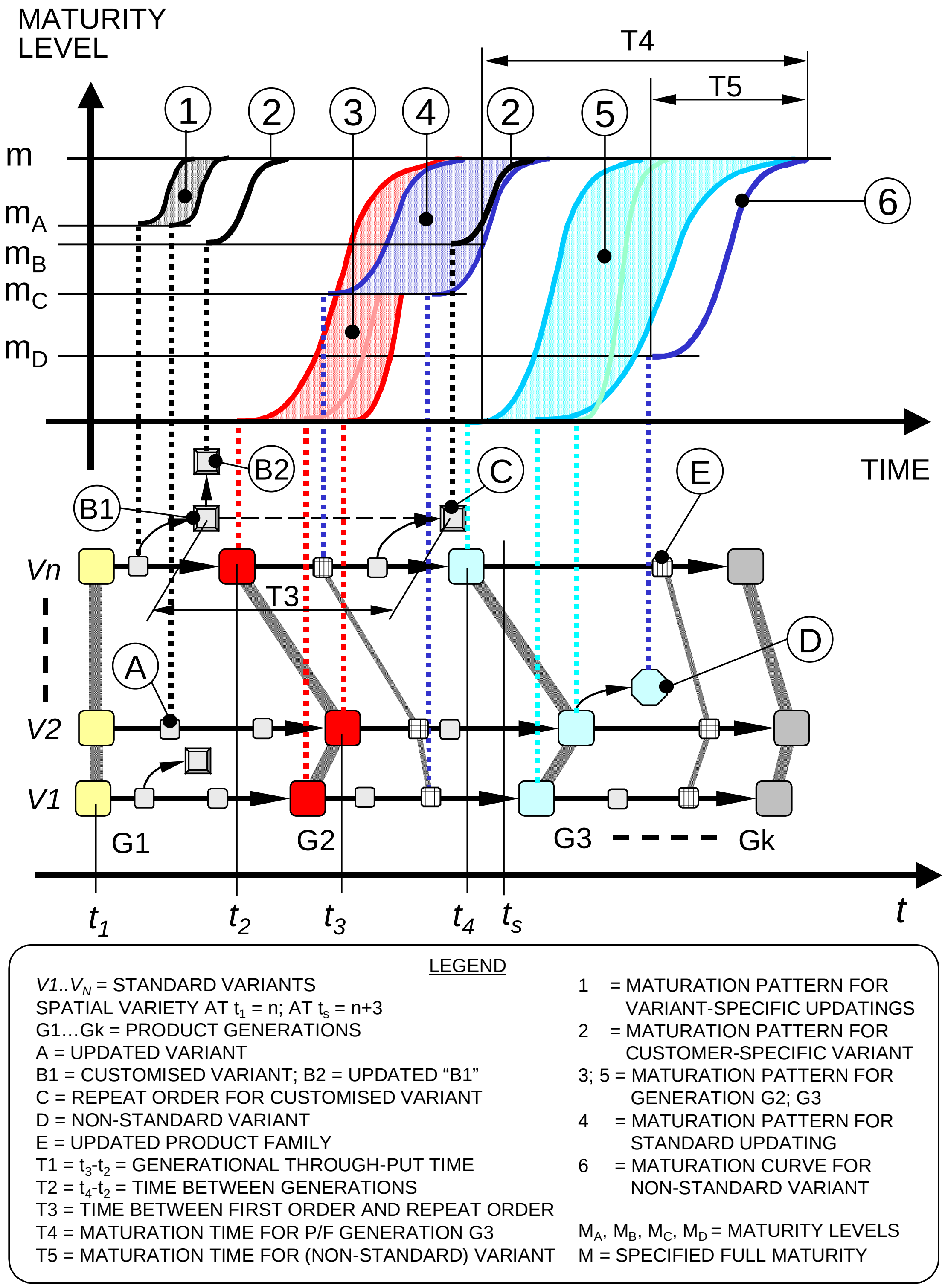

Figure 3. Variety in two dimensions, maturity levels and patterns.

4.2 From variety to variant mix

Variety is a momentary quantity. It is generated in a company’s product development function. The sales function, which is further down the process pipeline, uses this variety as a basis for making tender offers to the customers.

On the industrial market sales projects may take a long time, ranging from several months to years. Pending customer orders are often attached to a technical specification that stipulates many kinds of product properties. In other words, the contract specifies both the product variant and its developmental stage.

The sales function releases factory orders, which vary in scope and delivery time. There are many product variants, both in the spatial and developmental sense. When setting up the MPS, the factory must take into account its capacity, materials availability and other productional and logistical issues. Based on these, the production orders are released in a certain sequence. This means that the factory has its own definition of variety, which is concretised in the *variant mix*. It is the quantity and proportion of different product variants and their developmental stages. In a similar way, the factory has its own definition of maturation curves and patterns, which we call the *maturity mix*, Figure 4.

Maturity mix manifests itself in inaccuracies and deficiencies of variant-specific information. This generates a flow of feedback notes to product development process, during which the cases are processed based on priority. While the feedback notes are being processed, the factory needs to readjust its processes to cope with maturation-related information problems. Hence, the maturation time at the product development transmutes into a readjustment time at the factory.

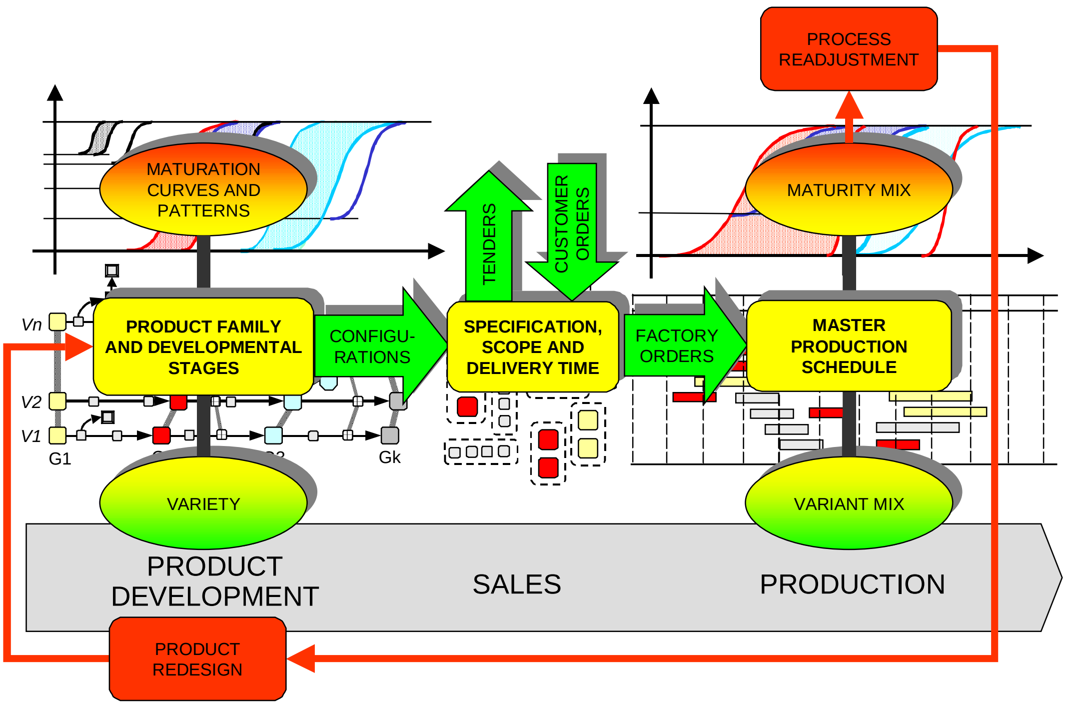

Figure 4. Aspects of variety and maturity.

5. Process view to variety

We define a *process* as a transformation, where energy, material and information are transformed from one state to another. In reality transformation is carried out by a set of structured activities to obtain a planned output from given input.

In a company, we connect such transformations to form longer, interrelated chains constituting the whole business process. There are numerous ways to establish, classify and organise processes, which, together with information flows, make the model very complex. The task is to find the best model to cope with the large product variety. Here we focus on the operative level, where the product is concretised from design to delivery.

The *product process* constitutes all the sub-processes needed in the product development to generate new and updated product designs. The *delivery process* constitutes all the sub-processes needed to sell, produce and deliver the product. In these two main processes a product takes its shape, beginning with abstract ideas and ending with a tangible set of structural elements.

5.1 Process and object knowledge

We apply two areas of knowledge to every object in the variant space:

1. Process knowledge. This covers all knowledge related to the process of creating an object. It can be dispersed into smaller parts, which we call sub-process knowledge. Process knowledge or any sub-process knowledge derived from it can be split into two components: general and object-specific.
2. Object knowledge. This covers all knowledge that specifies the object, and can be split into two components: general and object-specific.

General knowledge is universal and applies regardless of the object, whereas object-specific knowledge applies only to the object being considered. In the context of product family, the object means ‘product’ or strictly speaking ‘variant’. Instead of ‘general’ we use ‘standard’, which refers to the product master data. A ‘process’ can mean any process in company’s product or delivery process.

Figure 5 shows a single transformation process cut off from the company’s process pipeline. The variant mix being processed carries process and object knowledge. Object knowledge expresses itself in product-related information, such as drawings, parts lists, etc. Process knowledge expresses itself in process-related information, and it can be categorised into various sub-processes, such as order handling, engineering, purchasing, machining and assembling. Both information flows can be split into standard and variant-specific components.

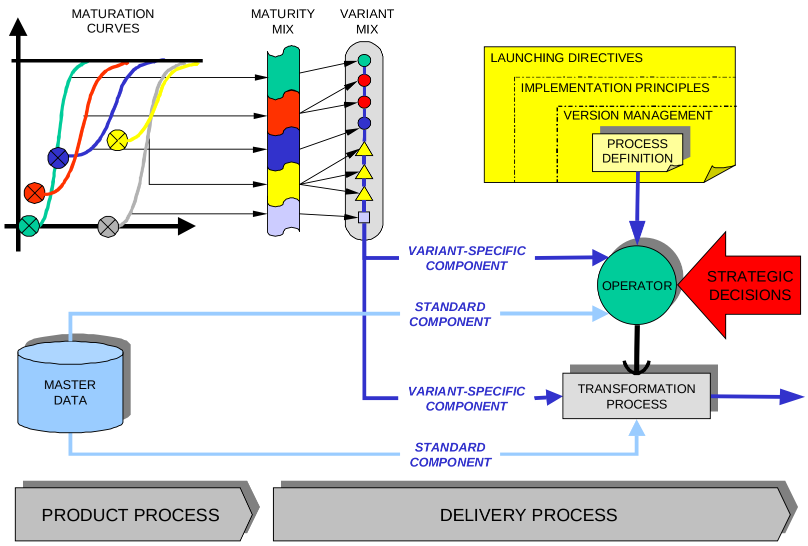

Figure 5. Variant mix carries process and object knowledge that influence both the operator and the transformation process.

Factory view

When a product is being designed, the object-specific knowledge is produced intrinsically. If spatial variety is equal to 1, all information can be regarded as standard, even after the release of new developmental stages. Nonetheless, developmental variety increases and the updated variants follow their maturation curves. Even though this increases the share of variant-specific information, the standard process definitions at the factory are usually flexible enough to allow small changes in the information.

If spatial variety increases, the amount of variant-specific information increases drastically according to maturation patterns. This can be seen in the factory as an increasing amount of incomplete drawings and work instructions. Hence, the problems arise with the maturity mix, as the factory has continuously in the manufacturing pipeline product variants that require variant-specific treatment.

5.2 Meetings of process and object

In the model of Figure 5, it is evident that the outcome of the transformation process depends on the following factors:

1. Process definition. This sets rules for operating the process. Flexibility is required to allow rapid changes in the process environment. Process definition must conform to company's launching directives, implementation principles and version management, which set guidelines and prescriptive rules for introduction of new developmental stages.
2. Accuracy of standard information and maturation pattern of the variant-specific information. The prevailing maturity mix is unforeseeable from operator's viewpoint. Inaccurate and distorted information results in wrong decisions by the operator or invalid output by the process.
3. Role of the operator. One operator may have various roles and responsibilities either in one or in other processes, in which cases any role can conflict with another. If there are several operators for one process, there is a risk that one operator dominates the others.
4. Strategic decisions. Rapid changes in the market situations may force the senior management to make strategic decisions, which short-circuit the written rules. The operator has no authority to deviate from the stated rules. This may lead to an unsystematic situation in the process pipeline.

5.3 Standard and specialised processes

Standard processes

The process model presented above constitutes *standard processes*. If we follow concurrent engineering principles in product development, all product-related and process-related information is formulated based on standard processes. However, in the course of time, prototype products, non-standard products and other developmental stages appear, bringing a multiplicity of incomplete product-specific information that is difficult or impossible to address efficiently by standard processes.

A remedy to this situation would be implementation of an efficient non-conformity handling process. Any time a maturation problem appears the process takes measures and corrective actions are initiated. At the same time, the process is readjusted to allow for preventative measures. This is one aspect that is emphasised also by formal quality management systems, like ISO 9001 [4].

Specialised processes

To support a formal quality management system and non-conformity handling process we can establish a specialised process for solving the maturation problems. It plays a leading role in troublesome situations and, if needed, interferes in standard processes. The specialised process needs to be broadly defined to ensure flexibility and agility. Its focus is in managing the introduction of new developmental stages and the prevailing maturity mix. The main tasks essentially cover estimating, planning, creating, executing and controlling.

The specialised process supports product planning, by setting up the product releases in factory's yearly action plans. It also estimates the impact of maturity mix when setting up the MPS. Furthermore, it engages the operators in an efficient feedback system, which helps in detecting design faults, and monitors redesigning.

There are, however, some issues that require special attention. Need for critical materials, special tooling, extra resources and transport arrangements must be forecasted for every planning period. Critical materials must be controlled throughout the logistics chain: their timely designing, purchasing and receiving must be ensured. Finally, the introduction of new work methods must be properly planned, and implementation of updated drawings and other engineering documents must be controlled.

6. Conclusion

Offering a large product variety is a competitive advantage for a company. To manage it efficiently, a configurable product family is suggested. Variety has two dimensions: spatial and developmental. Usually companies manage spatial variety without problems. Developmental variety is the result of successive developmental stages. Their inherent maturation patterns are charted through factory's variant mix into a maturity mix. This raises issues, which cannot be managed efficiently by factory's standard processes. To ensure preferential treatment for such issues, we suggest a specialised process.

References

[1] Wärtsilä Corporation: "Power on land and at sea." Available at <www.wartsila.com>

[2] Sanderson, S. W. – Uzumeri, M.: "The Innovation Imperative. Strategies for Managing Product Models and Families." Irwin Professional Publishing. Chicago.1997.

[3] Martin, Mark V., "Design for Variety: A Methodology for Developing Product Platform Architectures." A dissertation for the Degree of Doctor of Philosophy. Stanford University. November 1999.

[4] ISO 9001:2000(E), Quality management systems – Requirements

For more information please contact:

Seppo Suistoranta, Wärtsilä Finland Oy Turku Factory, Stålarminkatu 45, FIN-20810 Turku, Finland
Tel.: Int +358 10 709 3097, Fax: Int +358 10 709 3169, E-mail: seppo.suistoranta@wartsila.com