Re-qualifying Delivered Devices and Inventory for a New Product Specifications, a Case Study

Seppo Orsila[1]; Mika Aho[2]
1 CFO & Vice President, Modulight, Inc., seppo.orsila@modulight.com
2 Quality Engineer, Modulight, Inc., mika.aho@modulight.com

***Abstract* — The paper examines an e-Commerce system for re-qualifying delivered products and inventory for new product specifications, and proposes a streamline supply chain model with a mass-customization and a customer-direct capability. The paper also introduces benefits and foundation for a strategy for producing generic renewable designs.**

The empirical research was carried out by means of a case study in a Finnish SME that manufactures laser diodes for international markets. To provide a background, the product customization in a semiconductors industry, system analysis and architecture are addressed. The analysis and conclusions are based on the authors' experimental findings from this area. The study shows that a mass-customization is beneficial in the semiconductors industry as long as the laser diode designs are properly parameterized and structured in the database.

***Keywords* — E-commerce, Mass-customization, Supply Chain Management, Product development**

I. INTRODUCTION

A. Background of the study

A research [1] shows that responsive Sales Force Automation (SFA) has yielded few promising results. Usually it is difficult for customers to find proper information or a product, and make a selection between large number of product variants [2]. Today's customers are also aware of their buying options, with the requirements they place on suppliers often changing from order to order. This creates challenges but also huge opportunities for system developers, and to those manufacturing companies that can utilize for example the inherent process variation and production testing at individual entity level to their advantage cost effectively.

In response to such an unpredictable customer order cycle, companies are looking to reduce excess or unnecessary inventory – for example by eliminating the inventory entirely using a zero-inventory model [3]. This creates a demand for a mass customization (MC) system in modern economy where products need to be increasingly tailor-made to meet customer requirements. The system developed in the case company enables a customer-direct capability and a possibility for re-qualifying already delivered products or adjust the manufacturing process in-situ based on new customer requirements and quality control (QC) data. This can be particularly useful in manufacturing of devices with lots of critical variables in the specification. Very often customers require devices in small numbers and beyond the accuracy of today's production technology. Such customer requirements are mostly fulfilled by trial and error manufacturing or manually looking into QC data of previous production runs. The case company has realized the necessary architecture where the re-qualification of devices can be done semi-automatically and very large number of devices can be checked against desired specification.

Collaborative and build-to-order direct supply chains seem to have remarkable effects because of the advantages of the system integration. It takes the skilled managers to successfully engineer high-performance supply chains, ones that are built quickly, respond well, adapt well, and incorporate business intelligence. [3] Among many other companies, Dell, for example, has had success using this strategy in its build-to-order (BTO) scenario [3]. Traditional method of forecasting future demand and developing a production plan based on forecasts no longer works in the industry when shorter order-to-delivery cycles are required.

It is important to have responsive supply chains, which quickly and accurately respond to customer needs. It helps the company to keep promises and to know what production and distribution resources are available. The case company has developed a system that provides real-time integrated checks throughout the supply chain, from customer order to after-sales. The system can also help to set realistic order-delivery expectations as the required manufacturing steps to be performed are known, and the time to be processed can be estimated from previous production runs. The adaptive supply chain can be rapidly reconfigured to adapt to changing consumer demand. The rate at which the company can identify and respond to changing business conditions and consumer requirements can be accelerated.

Even though our examples are based on laser diodes we believe that the system is usable with little or no modifications to all process-role-entity type sectors with products and or services ranging from electronics to medical services.

II. PRODUCT CUSTOMIZATION IN SEMICONDUCTOR INDUSTRY

Semiconductor laser processes are like other semiconductor process vulnerable to process tolerance variations resulting in yield fluctuations but also largely variations in more application specific parameters such as emitting wavelength of the laser. This variation can effectively be used as competitive advantage when company has solid understanding of the individual devices history and other performance limits and that data is provided in usable format to business people [4].

The understanding is achieved through holistic information architecture that allows sophisticated matching of already manufactured devices against new or custom specifications such as those provided by company's space, medical and military customers. Increasing customization usually requires reorganization of the activity structures in production and distribution in order to enhance process flexibility [5]. We, however, have adapted in an early stage a generic process/sub process model, which supports modular product and process architectures, and logistics and suppliers configurations.

Some benefits of in-situ MC and build-to-order [6], [7] that can be applied in (semiconductor) industry:

- Made-to-order manufacturing largely minimizes the risk of forecasting and eliminates distribution stocks
- Increased flexibility and scalability can be gained by integrating customers early into product definition. Company can react fast to changing market trends
- Involving customers can lead to new products, product specifications and even innovations
- Reduction or elimination of inventory in distribution chain
- Helps in product differentiation and customer segmentation management

In general, the case company does not provide off-the-shelf products, but each product is more or less customized design. Some products are, however, manufactured in large quantities, which may provide a better price, but usually a compromise in the design. Truly customized products on the other hand provides better features but for a higher price. We have been experiencing Activity-Based Costing (ABC) [9] model in our environment, which can be used – in addition to internal cost management - to help customers understand how their behavior affects the costs of the product and service. The customers will then only pay for what creates enough value.

III. SYSTEM ANALYSIS AND DESIGN

We have found that *think big – start small* approach can be utilized after proper preparations as long as the architecture is holistic, generic and information is stored centrally only once. This sets the basis for building and further developing the system very good. It also ensures that all levels of planning are based on the same data. We have actually found out that by following these principles we have been able to increase productivity and relative gains from further systems development for several years now as our underlying architecture is just utilized more and more. We have also repeatedly observed that ROI-% rather increases overtime rather than stabilizes or declines with additional investment on top of the robust, core architecture.

In addition to the architectural aspects noted above we found that actual take-in-use time and system benefits are clearly influenced by information architecture consistency. Naming of information elements clearly is also essential for teaching users to serve themselves and get real user acceptance. In addition, no matter if the user interface is for customers or employees, the importance of training should not be underestimated.

No database implementation or representation can serve for sure the future needs of the enterprise. For this reason and for enabling users to make ad-hoc queries one needs to have structure that is simple enough. This enables the system to bend to changes in business. Yet it is important to maintain semantic enough structure for an average business user to comprehend and effectively use in her/his work. We also found out that simple structure based system is superior to typical big commercial system which has lots of rigidity and will not be able to quickly support changing business and operating models.

IV. SYSTEM ARCHITECTURE

A study [7] argues that MC is only possible if customer integration and co-process are supported by adequate systems being able to reduce the high transaction costs resulting from deem customer-firm interaction. The interaction systems for mass customization are the key instrument to reduce the costs. In literature [10] these systems are called configurators, choice boards, design systems, toolkits, or co-design platforms. No matter what the name is, the systems are responsible for guiding the user through the configuration process. The system may present different variations, provide more information, visualize the product, and show its pricing. The success of such interaction system is, however, by no means not only defined by its technological capabilities, but also its integration in the whole business infrastructure.

The system developed at the case company allows the organization to easily sell custom-made (semiconductor) devices by an advanced e-Commerce system that supports all important business functions and processes. The overall architecture aims to integrate company systems, various lifecycle issues of product fulfillment into a collaborative web-based system of interactive commerce, which supports

product customization over the Internet. Company's current holistic database-centered MES is efficiently linked with Product Data Management (PDM), Supply Chain Management (SCM) functions and Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM) systems [8]. The outcome is a system that practically serves every business process in company by truly transforming the business into e-Business.

All manufacturing functions are integrated to database-centered MES. The relational database stores all data related to products, production and product development, and helps the company to manage, monitor and control operations in real-time [8]. Information is stored on highly structured yet simple and non- redundant way, unlike in most commercial systems, which is one key to cost effectiveness and agility at system level. Product features, applications, and characteristics are parameterized in the relational database.

The company has been collecting measurement and production data since its birth in year 2000. The production equipment are integrated to databases, and measurement data – which is critical when verifying product specifications against the measurement data – is retrieved automatically from database tables. This makes the automatic generation of up-to-date real-time product datasheets easy, even with the smallest entity details. It also makes the marketing less expensive, much faster and more effective. The benefits for customer are clear from the fact that internal inspections, test and quality (ITQ) take their instructions directly from the same information source that was established by R&D and translated by marketing into a product specification.

The external toolkit (web shop) application is used to search product information from the web. It is linked to actual production database. From MC point of view, customers and other interested parties are able to query if a product configuration they have specified is available from the inventory and how many devices the company could ship immediately. Like in any other web shop, the products can be collected to cart, which later can be sent to the company. One of the limits of MC is that excess variety may result in an external complexity [6]. If the web shop is complex enough, the number of different configuration options might overwhelm the users. Piller [6] argues the customers should not start from scratch. In a good MC system there will be a pre-configuration which represents already a full configuration and which customers can modify according to their wishes.

The base of company's operations is a Universal Activity Management Tool (UAMT) [9] that connects together people, products, customers and other relevant entities. All the functions done in the company are based on activities. An activity can be anything from performing a process step in production, entering an supplier invoice, creating a quote, answering to customer inquiry, having a meeting, or doing an equipment maintenance. All the activities performed within the company are saved to a database with accurate information of date performed and time processed. The information can be later used in a decision-making for example by calculating the cost of the activity. Later non-value added activities can be eliminated and value-added activities improved.

V. STREAMLINE SUPPLY CHAIN MODEL

Like any other MC practice, selling laser chips requires information and co-ordination about the customer needs and desires in order to define a product specification or a product design. Thus the customer and supplier need to be in communication to complete the product development. The communication can be anything from a phone call or email discussion to e-Business system.

Currently there are hundreds of product specific parameters in our database that are more or less important when speaking of laser diodes and their characteristics. Development of a new laser diode chip may be time-consuming, but the results can be utilized in new product specifications later. Having well-structured laser design with detailed electro-optical and mechanical specifications in the database gives us increased possibilities for different kinds of database queries and data analysis.

The same existing product and process information can be utilized anywhere else too, for example when creating new process and sub process chains to manufacture the actual product. In general a laser diode manufacturing in our environment consists of some 200 different steps what we call sub processes. Depending on the workload, the actual manufacturing can take an equivalent of couple of working days if the product specification is already done.

In addition to manufacturing, the process step information can be used in cost management and profitability analysis as well. They work as a basis for accurate Activity-Based Costing [9]. In the same way the overall data serves marketing department needs too as the very accurate product specific information can be directly used in marketing materials.

Many MC approaches implemented in practice are based on offering a big amount of variety and choice [6]. However, there is only a little understanding about the customers, who often have no clear knowledge of what available solution might correspond to their needs. The newer and more complex the individualization possibilities are, the more information gaps increase [6]. Customers may simply lack the knowledge to transfer their personal needs into a concrete product specification if a simple product may become complex if one has to decide explicitly between all features. Semiconductor business, on contrary, is usually done between two companies and the buyers and sellers are familiar with the products. Requests for

quotations often come with a list of very detailed information, so in that sense customers have already a good knowledge what product might correspond to their needs.

Currently the e-Commerce system allows people to search products based on their main parameters and characteristics. If a product is found from the company's product portfolio, more information will be shown and the user can request for more details such as laser chip lifetime or measurement data. In case the product configuration does not exist, the potential customer is notified. If wanted, the requested parameters can be attached to product inquiry, which can be sent to the manufacturer for a closer review.

When the company receives an inquiry from the web, the system automatically creates a corresponding activity to company's CRM. The activity is created for a responsible engineer (in case of his/her absence, for a substitute person). All the necessary parameters, such as product line and product group, are added automatically.

When the responsible person opens the activity, the most suitable product can be quickly retrieved from a Manufacturing Execution System (MES). If a product specification is already available, its pricing history and stock quantity will be seen immediately. The power of the well-structured and parameterized laser diode product (specification) data comes when a product from the stock is not readily available. In that case the product engineers can check out from the database if such product with supplied specification has been manufactured before, or if there is a product close to its specifications.

When a suitable or close enough product specification is found, some changes to original specification may be needed. In that case the specification is duplicated and the changes are done to new specification accordingly. The duplicated specification will still have the information what process phases and sub processes were needed to create the product. Also information of possible subcontractors is found: who may have shipped the wafer substrate or have done possible packaging. This is important information since the laser diodes are qualified by the customer, and the manufacturing processes and wafer substrates affects to the product performance.

In the future the customers can interact with more advanced tool to define and translate their needs and desires into a concrete and a very specific product specification. Even now, the system turns a selling process into a co-design process and can help the company to capture important market trends information from their individual customers. Equally important is to learn from the customer, what might be their needs in the future. In the future we can allow the customers to do part of the specification work and translate those requirements at least semi-automatically to production.

Supply chain, however, is not finished until the product has been shipped to the customer. Usually this part of the model is the most difficult. Once the order is made from the supplier, the customer may pay well in advance for a product, and has to wait days, even weeks to get it. The supplier has to ensure that while the customer's expenditure is kept as low as possible, the value perceived by the customer has to be clearly exceeded [10].

VI. CASE EXAMPLE

A customer requested from the web 2-3 pieces of a custom 1-watt continuous wave multimode laser diode in the 1300 nm range. The supplier had done such laser before, but did not a product available in stock that could fulfill customer's request. The supplier however was ready to launch a whole new growth of wafer process to get the laser chip. After more detailed discussions with the customer, they provided main specifications as follows:

- Wavelength specification 1290nm – 1340nm
- Output power more than 0.5W (1-2W preferable)
- Any package with Thermo Electric Cooling (TEC)
- Devices needed to be from same wafer lot but test data needed to be available from multiple lots with a specific criteria for the manufacturing process of the lots

Based on specification parameters in the database, the supplier was able to find out whether an electro-optical specification that met the criteria was already found. Later – based on existing information – the supplier suggested doing a bonding on C-mount and to deliver the parts for mounting the C-mount on TEC. Supplier expected the lasers to reach over 0.5 watts having 1000mm cavity and 150 µm stripe.

In addition, the supplier had an ongoing project with following characteristics:

- Ith: below 1A
- Slope: ~0.3 W/A
- Center lambda: 1340-1360 nm
- Iop@1W CW: 4.5-5.5 A
- Aperture: 150x 1 micron
- Mounting p-side down

Having more discussions with customer, the actual need became for 1362 +/- 5nm fiber coupled laser diode. It was also necessary to have over 1 watt from the fiber. That would basically mean having ~1.5 watt output power from the ~200 µm laser emitter, with 400µm fiber size.

The supplier suggested sending 1-10 pieces of chips as prototypes. If they were not suitable, then the supplier

promised to quote 200 micron aperture devices with a customized wavelength. The original inquiries finally lead to new product at 1362nm wavelength and a significant order from the end customer.

The responsible product engineer was able to:

- Find out whether there already was a suitable design for the laser diode the customer requested
- Use existing electro-optical and mechanical specification
- Use the same instruction processes in manufacturing without a need to redesign the instructions
- Find out who was the best substrate (specific material) supplier for the requested design
- Send detailed lifetime and measurement data for the customer based on the previously manufactured product and its specification
- Give an estimated delivery date for the product
- Make profitability analysis of existing production activity data and use that in pricing as well

VII. CONCLUSIONS

Throughout the development of the e-Commerce system, we have learned that the best way to develop a system that supports each business process in the company is to use the same architecture and perform all functions within the system rather than outside the box.

Manufacturing companies are facing rapid and unanticipated changes in their business environment. The new competitive environment requires firms to produce products with a greater specificity to customer needs [5]. Companies that have just recently been mass producers of standard products are faced with situation in which they must provide highly customized products at sinking standard product pricing. When customers are more demanding and aware of their buying options, the supporting system development within the infrastructure becomes crucial. A poorly integrated technology infrastructure presents the same problem to supply chain performance as it does to company's internal performance. Poor systems integration means reduced flexibility and cost control. A company's ultimate success depends on its ability to collect, organize, and analyze data and to disseminate this information throughout the supply chain in a timely, cost-effective way [3]. Also the best and most advanced fulfillment system is worthless if it cannot express its added value to customer.

The value of a proper information architecture is not however limited or even mostly in ability to re-qualify devices against a new specification. The majority of the value is created as a result of capability to factually respond to verification and process related questions of customers as well as ability to differentiate products between applications and users. The proper architecture also sets a completely different level of possibilities for marketing management and other decision-making that wants to combine product data with business information without lots of manual, error prone work.

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