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Rapport

A Handbook for Product development using 3 Dimensional Concurrent Engineering

A Handbook for Integration of Product Design, Manufacturing Process Design and Supply-Chain Design in New Product Development Projects

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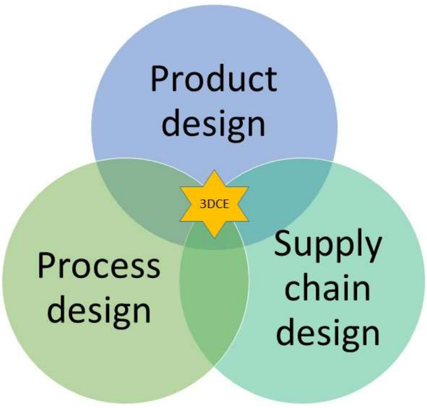

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This report is intended as guide for manufacturing enterprises wanting to try 3-Dimensional Product Development for themselves. It is built on experiences from a concrete Product Development Project, but here the participants have been anonymised.

The main results are a set of Guidelines for performing an effective 3DCE process, organised following a Stage-Gate process where there exists predefined given decision points (stages) in the product development process which must be passed.

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About the handbook

This handbook is intended to function as a simple guide that introduces key concepts related to PDC 3-Dimensional Concurrent engineering. It is not intended as a complete reference manual or an implementation guide. The contents described within are this handbook is provided as an easy introduction and way of reference to the concept.

The basis for this handbook is a research project supported by the Norwegian Research Council. The project's vision was to strengthen and further develop a competitive Norwegian manufacturing industry as a global provider of manufacturing products. A key overall objective of the project was to develop and test a method for parallel development of product design, production process and supply chain. By applying this method, the company seeks to increase revenue, reduce product cost, improve process stability, reduce time-to-market, and enhance the value chain integration. The experiences and lessons from this is summarised here in an anonymised document, for the benefit of all interested.

In the following the manufacturing company will be called Product Developing Company (PDC), subcontractors will be referred to as Subcontractor 1,2 etc. (SC1, SC2) and the participating research and development agency will be referred to as RDA. The project itself will be called Test Development when referred to. The description is kept general, suffice to say that it involved the development of a completely new product, with electronic, sensors, software and mechanical parts included.

This is a handbook, not a scientific paper. Hence we have chosen to keep references to a minimum. For those interested in 3DCE and the theories underpinning it we recommend a set of works in the section "Terms and definitions".

This handbook consists of 6 main sections:

Section 1: Terms and definitions
Section 2: New Product Development process
Section 3: The concept of 3DCE
Section 4: Implementation of 3DCE in practice
Section 5: Guidelines for performing an effective 3DCE process
Section 6: General advice and conclusions

1 Terms and definitions

1.1 Glossary

Channels - Means employed to distribute goods or services from producers to consumers.
Concurrent engineering - Integrated approach to product-design that takes into account all stages of a product's life cycle from design to disposal including costs, quality, testing, user needs, customer support, and logistics.
Customer relationship - The development of an ongoing connection between a company and its customers. The relationship involves marketing communications, sales support, technical assistance and customer service. The relationship is measured by the degree of customer satisfaction through the buying cycle and following receipt of goods or services. See also customer relationship management.
Design specification - Essential qualitative and quantitative characteristic that set criteria (such as performance requirements, dimensions, weight, reliability, ruggedness) to be satisfied in designing a component, device, product, or system.
Distribution - The movement of goods and services from the source through a distribution channel, right up to the final customer, consumer, or user, and the movement of payment in the opposite direction, right up to the original producer or supplier.
Enterprise Resource Planning (ERP) - Accounting oriented, relational database based, multi-module but integrated, software system for identifying and planning the resource needs of an enterprise. ERP provides one user-interface for the entire organization to manage product planning, materials and parts purchasing, inventory control, distribution and logistics, production scheduling, capacity utilization, order tracking, as well as planning for finance and human resources. It is an extension of the manufacturing resource planning (MRP-II). Also called enterprise requirement planning.
Feasibility phase - That precedes the design phase and in which the project concept is examined from different perspectives to assess the advisability of proceeding with it.
Flow - Movement of goods or services along the value stream from raw materials to the customer without backflow, stoppages, or waste.
Insourcing - Delegating a job to someone within a company, as opposed to someone outside of the company (outsourcing). One reason for insourcing to occur is if a company had previously outsourced a certain task, but was no longer satisfied with the work being done on that task, so the company could therefore insource the task and assign it to someone within the company who they believe will do a better job.
Inventory control - Activities employed in maintaining the optimum number or amount of each inventory item. The objective of inventory control is to provide uninterrupted production, sales, and/or customer-service levels at the minimum cost. Since for many companies inventory is the largest item in the current assets category, inventory problems can and do contribute to losses or even business failures.
Last time buy - manufacturer will call for a Last Time. Buy (LTB) where a business can make one last bulk purchase of the product before it is discontinued.

Lead time - Number of minutes, hours, or days that must be allowed for the completion of an operation or process, or must elapse before a desired action takes place. See also manufacturing lead time.

Lean manufacturing - Doing more with less by employing 'lean thinking.' Lean manufacturing involves never ending efforts to eliminate or reduce 'muda' (Japanese for waste or any activity that consumes resources without adding value) in design, manufacturing, distribution, and customer service processes.

Logistics - Planning, execution, and control of the procurement, movement, and stationing of personnel, material, and other resources to achieve the objectives of a campaign, plan, project, or strategy. It may be defined as the 'management of inventory in motion and at rest.'

Logistics channel - Network of all participants in a supply chain engaged in the receiving, handling, storage, transportation, and communications functions.

Manufacturing - The process of converting raw materials, components, or parts into finished goods that meet a customer's expectations or specifications. Manufacturing commonly employs a man-machine setup with division of labour in a largescale production.

New product development - Process of developing a new product or service for the market. This type of development is considered the preliminary step in product or service development and involves a number of steps that must be completed before the product can be introduced to the market. New product development may be done to develop an item to compete with a particular product/service or may be done to improve an already established product. New product development is essential to any business that must keep up with market trends and changes.

Outsourcing - The contracting or subcontracting of noncore activities to free up cash, personnel, time, and facilities for activities in which a company holds competitive advantage. Companies having strengths in other areas may contract out data processing, legal, manufacturing, marketing, payroll accounting, or other aspects of their businesses to concentrate on what they do best and thus reduce average unit cost. Outsourcing is often an integral part of downsizing or reengineering. Also called contracting out.

Process design - The activity of determining the workflow, equipment needs, and implementation requirements for a particular process. Process design typically uses a number of tools including flowcharting, process simulation software, and scale models.

Product specification - Written statement of an item's required characteristics documented in a manner that facilitate its procurement or production and acceptance.

Product design - The detailed specification of a manufactured item's parts and their relationship to the whole. A product design needs to take into account how the item will perform its intended functionality in an efficient, safe and reliable manner. The product also needs to be capable of being made economically and to be attractive to targeted consumers.

Product launch - The debut of a product into the market. The product launch signifies the point at which consumers first have access to a new product.

Product marketing - The overall process of conveying a good or service to customers. Product marketing includes defining the scope of the product line, identifying potential markets for a product, determining optimal pricing for the market, encouraging potential customers to purchase the product, and finding the best distribution methods for delivering the product to customers or to sales locations.

Procurement - The act of obtaining or buying goods and services. The process includes preparation and processing of a demand as well as the end receipt and approval of payment. It often involves

(1) Purchase planning,
(2) Standards determination,
(3) Specifications development,
(4) Supplier research and selection,
(5) Value analysis,
(6) Financing,
(7) Price negotiation,
(8) Making the purchase,
(9) Supply contract administration,
(10) Inventory control and stores, and
(11) Disposals and other related functions.

The process of procurement is often part of a company's strategy because the ability to purchase certain materials will determine if operations will continue.

Purchasing - The activity of acquiring goods or services to accomplish the goals of an organization. The major objectives of purchasing are to (1) maintain the quality and value of a company's products, (2) minimize cash tied-up in inventory, (3) maintain the flow of inputs to maintain the flow of outputs, and (4) strengthen the organization's competitive position. Purchasing may also involve (a) development and review of the product specifications, (b) receipt and processing of requisitions, (c) advertising for bids, (d) bid evaluation, (e) award of supply contracts, (f) inspection of good received, and (g) their appropriate storage and release.

Sales forecast - Projection of achievable sales revenue, based on historical sales data, analysis of market surveys and trends, and salespersons' estimates. Also called sales budget, it forms the basis of a business plan because the level of sales revenue affects practically every aspect of a business.

Single sourcing - Practice of using one supply source without a competitive bidding process for a justifiable reason.

Sole source - One and only one source that possesses a unique product having singular characteristics or performance capability.

Stage gate process - A stage gate process (also referred to as waterfall process), is a project management technique in which an initiative or project (e.g., new product development, software development, process improvement, business change) is divided into distinct stages or phases, separated by decision points (known as gates). At each gate, continuation is decided by (typically) a manager, steering committee, or governance board. The decision is made on forecasts and information available at the time, including the business case, risk analysis, and availability of necessary resources (e.g., money, people with correct competencies).

Supplier - A party that supplies goods or services. A supplier may be distinguished from a contractor or subcontractor, who commonly adds specialized input to deliverables. Also called vendor.

Supply chain - A supply chain is a network between a company and its suppliers to produce and distribute a specific product, and the supply chain represents the steps it takes to get the product or service to the customer. Supply chain management is a crucial process, because an optimized supply chain results in lower costs and a faster production cycle.

Value stream mapping - A way to keep track of goods and materials as they move through the product creation process that helps a business boost productivity and reduces waste. A typical value stream mapping process will begin with the delivery of raw materials, proceed through intermediate states of production, and then conclude with the creation of a finished product ready for sale to consumers.

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2 The New Product Development (NPD) process

New product development is typically a huge part of any manufacturing process. Most organizations realize that all products have a limited lifespan, and so new products need to be developed to replace them and keep the company in business. Just as the product life cycle has various stages, new product development is also broken down into a number of specific phases.

A number of detailed NPD models have been developed over the years, one of the most cited which is the Booz, Allen and Hamilton (1982) model, shown in Figure 1, which underlies most other NPD systems that have been put forward.

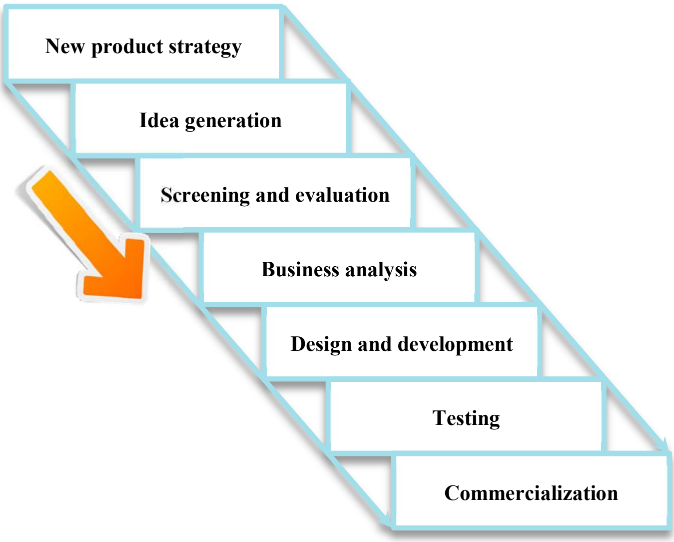

Figure 1 Stages of New Product Development (NPD) (Booz, Allen & Hamilton, 1982)

PDC (The manufacturing company) combined the 3DCE approach with a Stage-Gate Product Innovation model, this latter being the main company framework for its product development system. A Stage-Gate System is a conceptual and operational road map for moving a new-product project from idea to final launch. Stage-Gate divides the activities into distinct stages separated by management decision gates. The Stage-Gate Product Innovation system has been referred to as the single most important discovery in product innovation – empowering between 70 and 85% of all North American companies to achieve improved returns on their product development dollars and to achieve new growth[1]. It is further discussed in section **Implementation of 3DCE in practice**.

[1] http://www.prod-dev.com/stage-gate.php

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3 An Introduction to Three-dimensional Concurrent Engineering 3DCE

3DCE has its roots in concurrent engineering, which presumes that products and processes should be designed simultaneously, involving multi-functional teams early in the process, which may include suppliers and customers.

Concurrent engineering is a work methodology based on the parallelization of tasks (i.e. performing tasks concurrently). It refers to an approach used in product development in which functions of design engineering, manufacturing engineering and other functions are integrated to reduce the elapsed time required to bring a new product to the market. "Three-dimensional concurrent engineering (3DCE) is a relatively new concept, coined by Fine (1998).

Fine introduces a simple, yet powerful model of NPD supported by concurrent engineering, in which the traditional focus on an appropriate match between product and process is augmented by an additional consideration of supply chain configuration. Three-dimensional concurrent engineering (3-DCE) extends this concept from products and manufacturing to the concurrent design and development of capabilities chains.

In particular, once one recognizes the strategic nature of supply chain design, one feels almost compelled to integrate it with product and process development. The additional element of 3DCE, added by Fine (1998), supply chain design considers the aspects of sourcing decisions, contracting decisions (type of relationship an organization has with other members of the SC), make-buy decisions (insourcing or outsourcing), coordination decisions (logistical channels, suppliers and customers).

The essence of 3DCE lies in iterative processes where decisions on desired results are arrived by repeating rounds of analysis or a cycle of operations, within each stage. The objective is to bring the desired decision or result closer to discovery with each iteration. The iterative process can be used where the decision is not easily revocable or where the consequences of revocation could be costly. However, constant iterations can also be costly and the process must stop at some time. Stopping points is defined in the form of stage gates in the Stage-Gate. At each gate work is summarised and the iteration stops when the gates is passed.

A new stage opens for a new iterative process, with new goals, activities, actors and plans. Employing the 3DCE in a Stage-Gate model we get a series of iterative improvements where each iteration is closed by the stage gate.

We also get a set of decision points as gates, where information is brought together, synthesised, organised and evaluated by the actors. This information and these decisions now form the new starting point for the next iterations.

There are many possible linkages between and among the product, process, and the design of the supply chain. Some of the linkages are shown in Figure 5. This figure also shows the interface points and key issues in designing the product, the process, and the supply chain. For example, the key issue in simultaneously considering product and process design is concurrent engineering. While 3DCE is not widespread, it has been used successfully by some firms in practice. For example Intel and Chrysler have used 3DCE particularly in the area of NPD. The three elements of 3DCE are the following:

Product design is divided into activities related to product architecture, whether the product is integrated or built up of modules, and activities related to the detailed design such as performance and functional specifications.
Process design is divided into the development of unit processes (that is, the process technologies and equipment to be used) and manufacturing systems development—decisions about plant and operations systems design and layout.
Supply chain design is divided into the supply chain architecture decisions and logistics/coordination system decisions. Supply chain architecture decisions include decisions on whether to make or buy a component, sourcing decisions (for example, choosing which companies to include in the supply chain), and contracting decisions (such as structuring the relationships among the supply chain members). Logistics and coordination decisions include the inventory, delivery, and information systems to support ongoing operation of the supply chain.

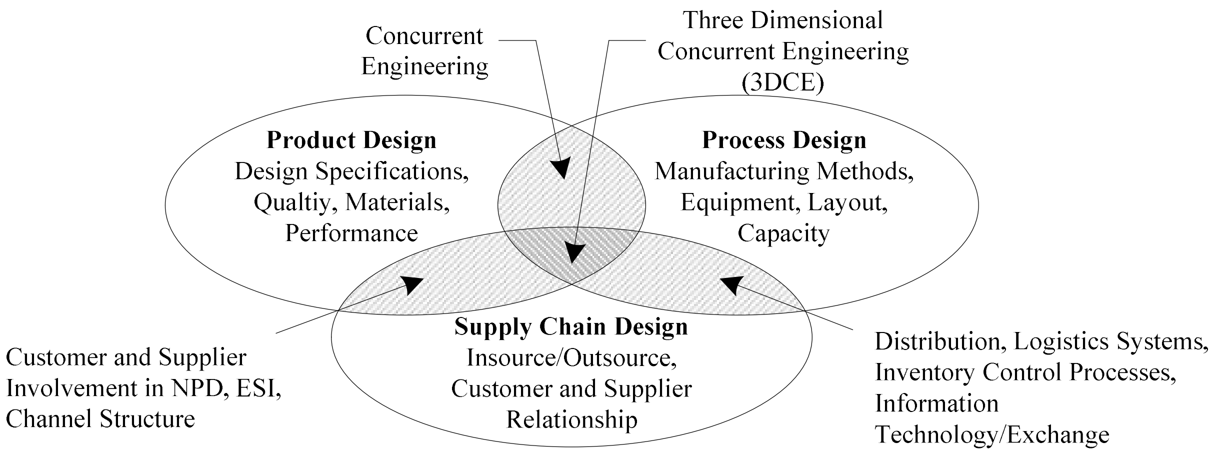


Figure **2** Three dimensional concurrent engineering (Elram et al., 2007)

There is limited knowledge of how these three areas influence each other and there are no concrete methods and guidelines for how to achieve such parallel development in practice. However based on the literature, there is substantial grounding for 3DCE and evidence that it should provide beneficial outcomes to organizations. 3DCE is not simply a supply chain management tool. The successful implementation of 3DCE requires top management support as well as functional support.

The overall idea for value creation in Test Development is to develop and test a method for parallel development of product design, production process design and supply chain design. By applying this method, PDC seeks to increase revenue, reduce product costs, improve process stability, reduce time-to-market, and enhance value chain integration.

4 Implementation of 3DCE in practice

In this section is the practical case based on 3DCE practices within PDC is presented. The empirical basis for this section is direct participation in the development project, both in the product development and supply chain design. As part of the development work the authors and colleagues at the research institution have conducted analysis, carried out tests and experiments and helped shape the overall new product. In addition we have added several other sources of data like interviews, document analysis, observation and meetings with PDC and suppliers. The text has been written by a group of researchers, but has been through several revisions and discussions with the industrial partners in order to ensure it gives a best possible description and a set of advice that is useful to product development in manufacturing.

The 3DCS model within PDC can be illustrated in the following way, see figure 3.

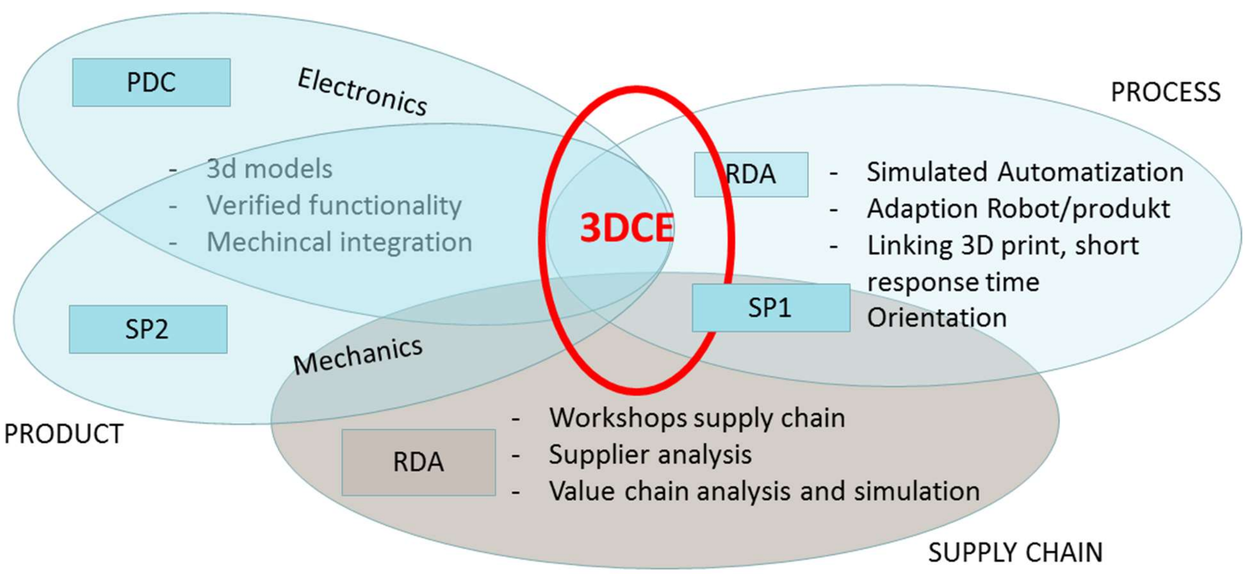


Figure 3 DCE model within PDC for the Test Development project

The discussions in this section comprise two main areas:

1. Implementation of 2-dimensional concurrent engineering: parallel development of product design and manufacturing process design
2. Adding the third dimension: integration of supply chain design in the above-mentioned process

4.1 2-Dimensional Concurrent Engineering - Product design/process Design

The overlap between product and process deals with the technology, the specifications, and the process technology and equipment to be used. Developing a close link between product and process design results in better overall operating performance on several measures including cash flow. The major rationale for concurrent engineering (CE) is to shift away from a serial “over the wall” approach to parallel processing of activities. As usually practiced, CE attempts to bring more feedback upstream earlier, generally through face-to-face meetings. In PDC, design of Electronic, SW, mechanic and assembly line (Production) are done in parallel.

An important stage in the product development process is the concept development phase. During any new product development project, the team must identify the markets, technologies, and product categories that frame the innovation effort. A product concept statement must be developed which is a verbal or prototype expression that explains what is going to change in the product or service and how the customer stands to gain from the change. The product concept statement should clearly identify the benefits of the product (in the words of a potential customer), what form the product design will take, and the specific technologies required to fully develop and commercialize the new product.

The Toyotas Set Based Concurrent Engineering (SBCE) process, which is known as a best practice within the manufacturing industry, is to a large extent based on parallel processes; lower level of linearity and single solutions or points. The SBCE process starts with contemplating a large set of possible solutions which will be gradually narrowed down to the final solution. By gradually eliminating the weaker solutions, the probability for finding the best possible solution increases. As a result Toyota can spend more time on defining the solutions in the front end phase in order to move faster towards convergence and final production in comparison to its competitors who are still using the traditional point based approach.

In communicating the design alternatives, the number of alternatives for a combination of solutions quickly increases into large amount of rules and data and it is not always possible for the actors to make the final decision within reasonable time. Therefore there is a need for excluding the solutions that are not compatible. To reduce the number of solutions, two different approaches can be used: one approach is to **identify the designs violating the constraints and requirements**. The second approach is to **find the intersection where members of the individual sets are compatible** i.e. where solutions are capable of interacting and operating with each other.

Identifying the designs violating the constraints and requirements can be done through application of a matrix for communicating design alternatives, where the potential solutions are evaluated based on a set of criteria such as functionality, cost, space, etc. (See figure 4).

Evaluation criteria						
Potential solutions		Function 1	Function 2	Cost	Space	Etc.
	Solution X	❍	❍	∆	X	
	Solution Y	∆	X	♦	❍	
	Solution Z	❍	∆	∆	♦	

♦ - Excellent ❍ - Acceptable ∆ - Marginal X - Unacceptable

Figure 4 Matrix for communicating design alternatives

Then the members involved in the design process, develop and communicate a set of solutions in parallel and rather independently. As the design process proceeds, the design team will gradually narrow down the set of solutions based on additional information from development, test, customers and other involved actors. As the design converges and becomes clearer, the involved actors should stay committed to the finalized set of solutions for the others to be able to trust the communicated information. It is important that all three disciplines participate in the formulation and evaluation of these solutions. Otherwise we risk suboptimal solutions.

Figure **5** presents an example of the application of SBCE:

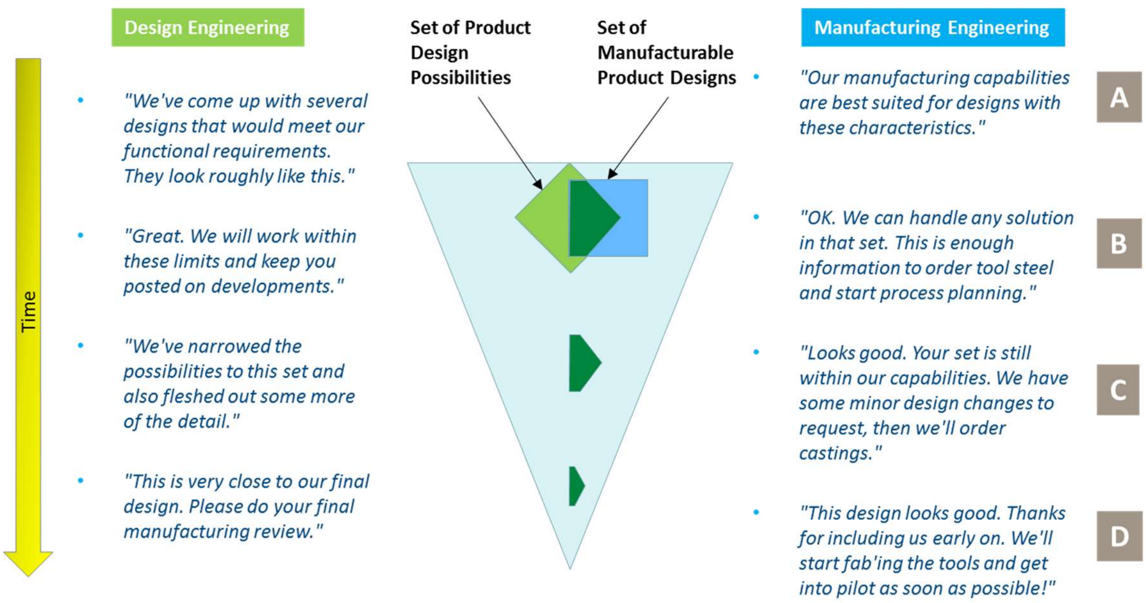


Figure 5 *Example of SBCE manufacturing process design*

PDC's practices regarding SBCE principles, which is referred to as a well-known best practice within the manufacturing industry and the suggestions for improvement are presented in

Figure **6**

TOYOTA SBCE principles	Actions	Areas for improvement
1. MAP THE DESIGN SPACE. • Define feasible regions. • Explore trade-offs by designing multiple alternatives. • Communicate sets of possibilities.	• PDC and SC1 have come up with suggestions (mechanics and electronics parts) - RDA RDA has assessed the manufacturability of the product • PDC and SC1 have developed prototypes, RDA RDA has tested prototypes, PDC, SC1 and RDA have discussed design options (solutions) continuously during the process.	Development of product checklists (for functionality) in cooperation with Suppliers and product design team Design of matrix for communicating design alternatives in a more systematic way. Extended choice of suppliers (avoiding sole sourcing)
2. INTEGRATE BY INTERSECTION. • Look for physical intersections of feasible product sets. • Impose minimum constraint. • Seek conceptual robustness.	Solutions / opportunities have been discussed early in the process among all stakeholders to come up with a "solution package" that satisfies everyone. Toyota gives full power to its suppliers as long as they cover Toyota's needs and standards. This resonates decision-making times for Toyota and saves time. In Test Development, most the decisions have been made by the project owner (PDC). Flexible product specifications have created possibility for not being locked with a specific solution, however unclear	Clear requirement specifications in the front end phase. Conceptual robustness; a product with varied features in order to meet the requirements of different interest groups.

	requirement specifications has led to delays in the design and development process.	
3. ESTABLISH FEASIBILITY BEFORE COMMITMENT. • Narrow sets gradually while increasing detail. • Stay within sets once committed. • Control by managing uncertainty at process gates.	Product features have been discussed and modified gradually to reach an optimal solution. Options have been effectively communicated between the actors. Changes have not been made unless relevant actors have been informed.	Despite the fact that the design process should develop gradually, it is important that decisions are made so that manufacturing starts as soon as possible. More frequent milestones with less time in between; More often prototype testing

Figure 6 PDC's practices vs Toyota SBCE principles

Such effective integration of product design and manufacturing process design will result in the release of more mature product designs which can be more effectively produced within a company's existing or planned production system and more effectively supported.

New product design and introduction lead time or time-to-market will be reduced to meet rapidly changing technology and customer demands and increase enterprise flexibility. The accomplishment of these goals requires an integrated approach to product and process design which considers the company's business strategy. This integrated approach to product and process design is dependent on the following aspects:

1. Alignment of product and process design approach with the organization's business strategy;
2. Organizational integration using product development teams or integrated product teams as a way to organize development activities;
3. A well-defined and optimized development process;
4. Optimization of the product and process design to enhance manufacturability, testability, affordability, reliability, maintainability, etc.

Test Development project followed an iterative development process for integrated product and process design. At every design iteration, a design review was organized with designers from PDC and SC1, production people from PDC, and RDA. The reviews were based on a custom excel sheet that has been developed over time at RDA and was adapted to the project Feedback from these meetings were noted and considered immediately by the designers. The production system development followed a four-staged process at every iteration. This process was maintained and refined during the entire life-span of the project.

Error! Reference source not found. summarizes the integrated product and process development process.

1. Establish/revise process model. The intention of this model is to formalize the description of all the process steps necessary for manufacturing of the product. The process model was implemented as an IDEF0[2] model.
2. Establish capacity model based on the process model given the process steps defined in the process model. In the Test Development project, tailor made Excel spreadsheets were used for capacity modelling.
3. Develop/update production system concept based on the system configuration defined in the capacity model.
4. Visualize the production system concept by 3D modelling and simulation on system level. In the Test Development project, Visual Components was used for 3D visualization. Figure 4 shows a modified segment of a 3D model test results which generates feedback on manufacturability issues to the product development process.

At the assembly level, at every design iterations, the following steps were executed in parallel:

1. Part and assembly study and development/update of assembly solutions
2. Design/redesign of jigs and grippers and programming of robots.
3. Automated assembly of prototype and testing of robotic programs, sensors, grippers and jigs.
4. Analysis of the results and feedback to engineering process

[2] ICAM Definition for Function Modelling

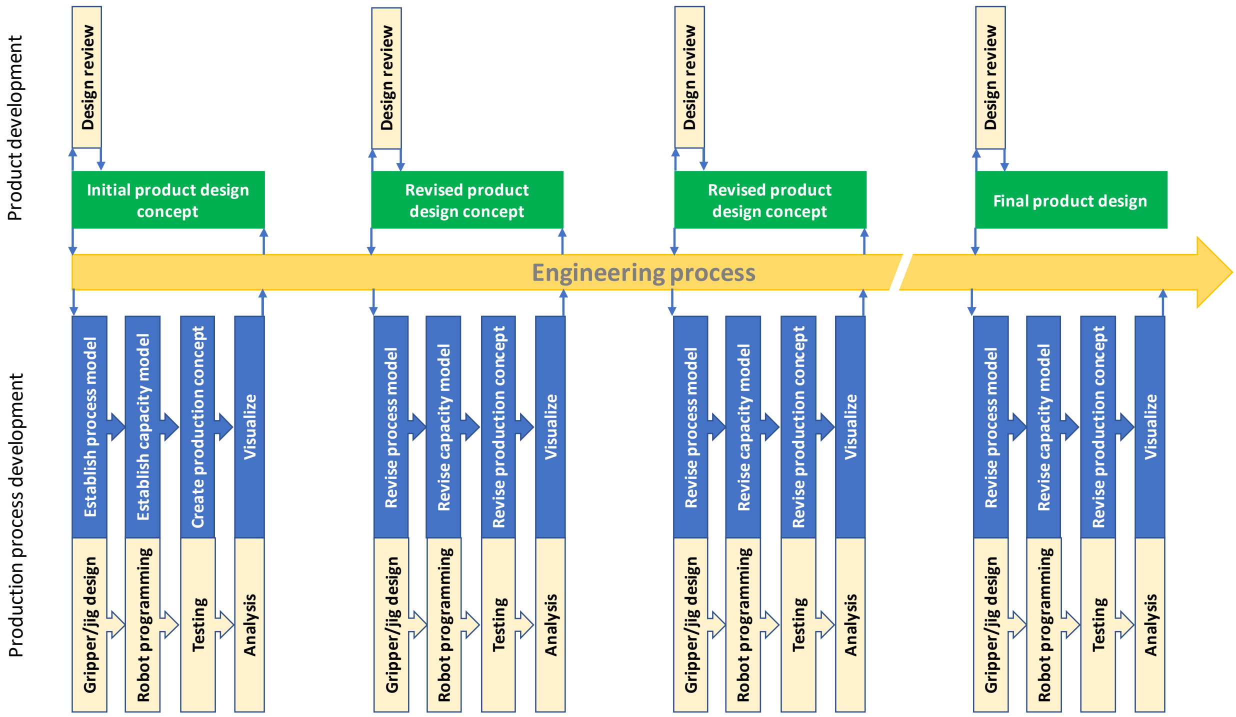


Figure 7 Parallelism between product development and production process development

The next section deals with the integration of the third core concept of 3DCE with the above-mentioned concepts and an explanation on how parallel development of supply chain design alongside product and process design procedures can lead to added value for the company.

4.2 3 Dimensional Concurrent Engineering (Product design/process Design/ supply chain design)

The conventional approach to NPD involves the assignment of representatives from support functions to review and recommend changes as the project evolves. This approach is costly and time consuming due to the iterative nature of NPD.

The Time to Market (TTM) and the cost of NPD can be reduced considerably by involving the support functions to a greater extent and also earlier in the NPD process. In fact the supply chain management should no longer need to clean up after NPD, but instead be involved from beginning of product development, with the same level of authority.

As mentioned in the previous section, one of today's practices in the NPD area is the concurrent engineering practice. However concurrent design has mostly focused in internal collaboration while today's global competition requires concurrent design to be a collaboration in the entire demand-supply chain, as it is an important key to success and profitability. This has in fact been the main motivation for integrating the supply chain design with the product and process design through the

NPD process in PDC. Before moving on to the discussion on the practices in 3DCE, some facts about PDC's supply chain will be indicated.

***Suppliers*[3]**

There are mainly five segments of suppliers. Four of which are raw materials for production and the fifth, third-party products, that are not produced internally in PDC. Components and parts located in the raw materials stock before production are throughout this thesis referred to as raw materials. The largest suppliers of raw materials are located in Norway, but some parts are bought outside of Norway as well.

Operations

Operations is the part of PDC who is responsible for the internal operations of production, inventory, logistics, and the order process, as well as purchasing and supplier relationships. The Operations does also cover the operations in other cities.

Production line

Production is divided into four production departments, named production lines throughout the thesis. Each of which has different characteristics in regard to products and production processes.

In the previous section the link between product design and process design was explained and the practices within PDC and areas for improvement where discussed. Following, the required practices towards effective involvement of supply chain in the product design and process design will be discussed. This is based on the real practices in PDC throughout the Test Development project.

Adding the third dimension (supply chain design)

As earlier mentioned, the essence of 3DCE lies in iterative processes where decisions on desired results are arrived by repeating rounds of analysis or a cycle of operations. The objective is to bring the desired decision or result closer to discovery with each iteration. Including design of the product's supply chain in this process is intended to reduce costs and simplify logistics operations.

Both upstream or supply and downstream logistics should be considered. Market conditions will determine whether the product must be delivered on demand or if the producer may operate with a delivery time greater than shipment time. This lead time on delivery will determine whether the producer need to carry stock to cover demand or if products may be produced on demand. Usually buffer stocks are determined based on an assumed service level. Carrying variants of the same product will increase the size of total buffer stocks more than the increase in market coverage and demand.

[3] The description of suppliers has been simplified somewhat to keep anonymity of participants.

Careful considerations of what products need to be carried in stock are always necessary. On the other hand, modular designs and stocks of intermediate products are sometime used to reduce production lead time sufficiently to finish products on demand. Traditionally many products are produced in batches due to machine changeovers. With designs for automated production changeover times might become negligible thus in effect reduce batch sizes to one product at a time. With no changeover times and short production times all orders can be fulfilled by products made on demand, if adequate supplies or intermediate products are available.

The relationship between lead time and the need to carry buffer stocks also exits on the supply side. The producer need to keep adequate buffers of inputs for all kinds of products while they are waiting for new supply. In a normal value chain, the batch sizes and thus lead time will increase as production characteristics upstream move towards process industry. A significant part of the lead time is however usually reserved by the supplier as administrative lead time, i.e. leeway to plan production. The lead time on supplies may be reduced by offering the supplier information on forecasts and plans thus leaving him time to plan his own production accordingly.

Cooperation in the form of increased visibility and predictability is however only possible with a few selected suppliers. The trade volume with such partners need to be significant for both parties. For the predictions to be meaningful, the number of suppliers need to be small, preferably single supplier.

Market conditions may dictate that some parts need to be bought in the open market (at arm's length) and some suppliers may have notoriously long lead times. These conditions are usually known beforehand and should influence the choices made in the supply chain plan. Identification of critical parts and long lead time items are therefore part of the early part of the stage gate model.

PDC has long incorporated unique identifiers (product numbers) in their products. The identifiers have however been programmed in the logical circuits of the product and is thereby only readable by connecting to the unit. The cost of passive RFID chips has come down through the maturing of the technology and provide means for identifying products in situ.

Before, proceeding to the suggestion on main improvement actions for incorporation of supply chain into the two above mentioned dimensions, the stage-gate process for driving new products to the market will be briefly described.

A Stage-Gate System is a conceptual and operational road map for moving a new-product project from idea to final launch. Stage-Gate divides the activities into distinct stages separated by management decision gates. Cross-functional teams must successfully complete a determined set of related crossfunctional activities in each stage prior to obtaining management approval to proceed to the next stage of product development (See figure 8).

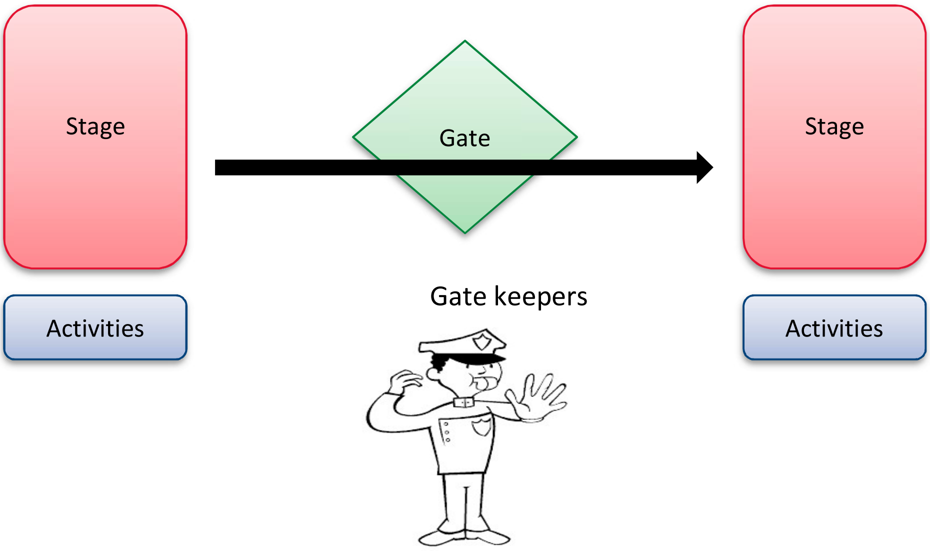


Figure 8 The Stage-Gate (R) process

Stages are where the action occurs. The players on the project team undertake key activities to gather information needed to advance the project to the next gate or decision point. Stages are cross-functional (there is no research and development or marketing stage) and each activity is undertaken in parallel to enhance speed to market. To manage risk, the parallel activities in a certain stage must be designed to gather essential information - technical, market, financial, operations - in order to reduce the technical and business risks. Each stage costs more than the preceding one, resulting in incremental commitments. As uncertainties decrease, expenditures are allowed to rise and risk is managed.

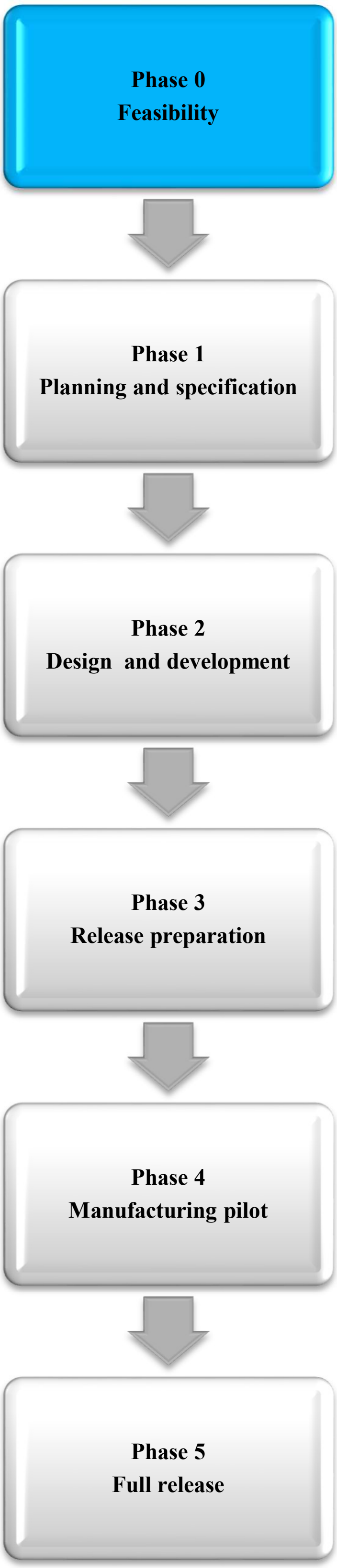
In the following section, the key stages within the stage gate process, the main goal for each stage, activities, gate keepers and the improvement actions which ensures the incorporation of supply chain design with product and process design actions within the stage gate process.

5 Guidelines for performing an effective 3DCE process

In this section, the stages are based on PDC's stage gate model and the 3DCE guidelines are specifically pointing to the areas where a manufacturer needs to pay attention, based on the information acquired through the interviews and simulation model done within the project. The integration of the logistics and supply chain management thinking into the product and process design should ensure that the resources and capacity of a manufacturer can meet the expected demand

Starting at next page the tables presents the stage-gate model, summarizing the goals, involved actors, activities, and 3DCE tips at each phase of the model.

5.1 Phase 0. Feasibility



Goal

Clarify target market and product concept that could provide viable solution.

Activities

- Research to determine market opportunity
- Creation of Business Opportunity Proposal (BOP)
- Creation of Voice of Customer requirements (VOC)
- Concept identification
- Assessment of alternative concepts
- Assessment of potential risks

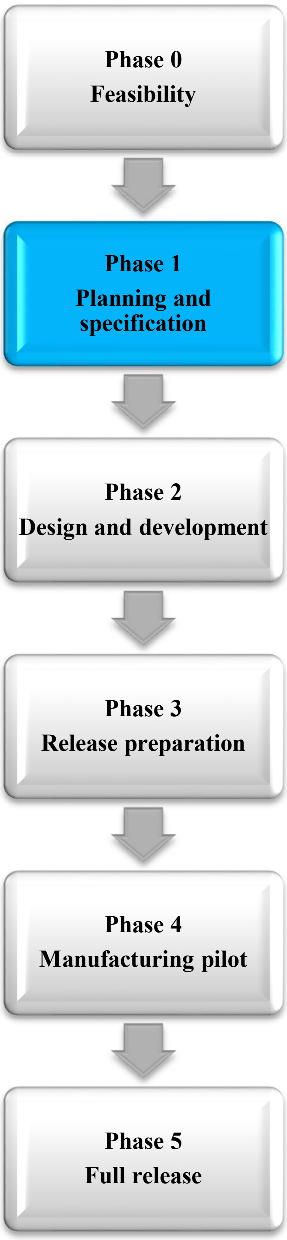
Main actors

- Technology (R&D)
- Product marketing
- Operations
    - Production management
    - Purchasing/supply chain management
- Customers

3DCE guidelines

- Involve procurement team in order to evaluate supply capability for long lead time and critical components sourced by existing suppliers. This is done in order to avoid dependence on unreliable supply.
- Develop a rough cut version of the product design
- Involve potential customers in the investigation phase in order to receive feedback on improvement of the innovation quality (ideas on customer delighters)
- Communicate VOC to the design team by the marketing section
- Involve the supply chain section for forecasting the customer demands
- Evaluate prospected sales and required production capacity. Investigate effects on product availability in time, cost and input requirements. (Rough-cut capacity planning)

5.2 Phase 1. Planning and specification



Goal

Develop detailed product requirements, a resourced program plan, & business case while demonstrating Technology Readiness via prototype tests

Activities

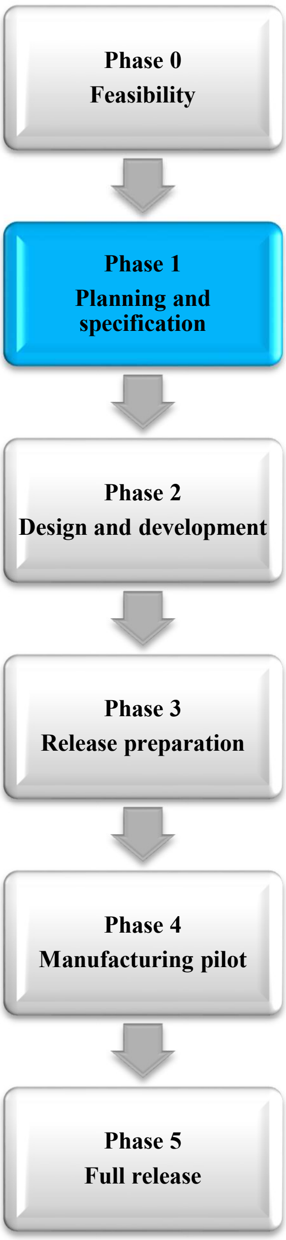
- Validation of product requirements and develop design & reliability document (D&R) or agreed to terms of reference (ATOR)
- Clarification of the final concept
- Revision of Business Opportunity Proposal (BOP) based on the information acquired in the feasibility stage
- Assessment of Technology Readiness Level (TRL)
- Preparation of the Capital Appropriation Request (CAR)
- Assessment of manufacturing process implications
- Design of System / components

Main actors

- Technology (R&D)
- Product marketing
- Operations
  - Production management
  - Purchasing/supply chain management
- Manufacturing and assembly
- Suppliers
- Customers

3DCE guidelines

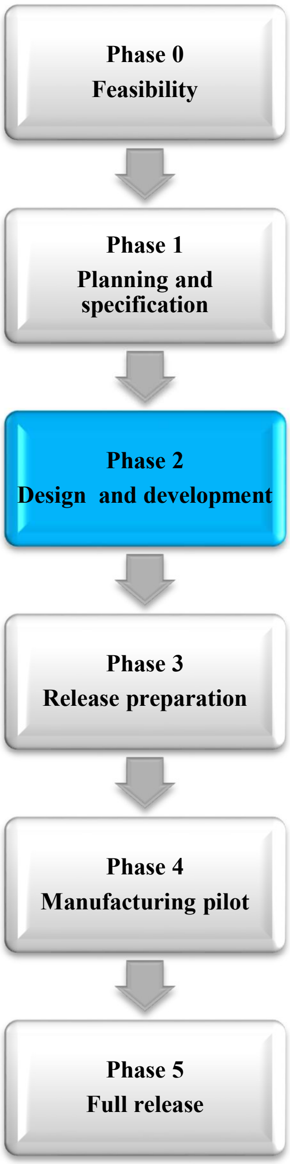
- Each discipline must allocate a person with responsibility for the process, in order to serve as a contact point and to ensure that the needs/involvement of this discipline is taken into account in the work
- Involve the procurement team in the decision on the choice of suppliers in order to ensure that the suppliers are qualified regarding the organization's policies; ISO9001 certification, financial check; MKO denial check.
- Ensure clarity of product specifications and the compatibility of the chosen material with the manufacturability of the product through 3D modelling and rapid process design simulations.



3DCE guidelines continued

- Involve the supply chain design team to ensure that the design is not dependent on raw material and components with challenging availability. Ensure that the commodity strategy is followed carefully; gathering the best suppliers within each technical area. In case there is no other choice than single sourcing, ensure suitable agreements in place. Example: A microcontroller in the new product is produced by one specific supplier. The supplier should then provide a guarantee for delivering the component as long as the company needs it. This however is always a risky situation that should be avoided when possible
- Estimate the material and other input costs based on information received from the product design team based on forecasted demand and probable supply chains.
- Develop a master plan for all disciplines and production groups to ensure that the resources and capacities match with the estimated customer demand. Ensure accurate forecast of customer demands used in the plan.
- Involve the supply chain design team to make appropriate distribution agreements and plans (language, market requirements, toll, transportation means etc.). For example, choose packaging materials compatible to the temperature and other conditions in the customer's country.

5.3 Phase 2. Design and development



Goal

Detailed design and validation (via Engineering Check Sample - ECS) to optimize the design solution

Activities

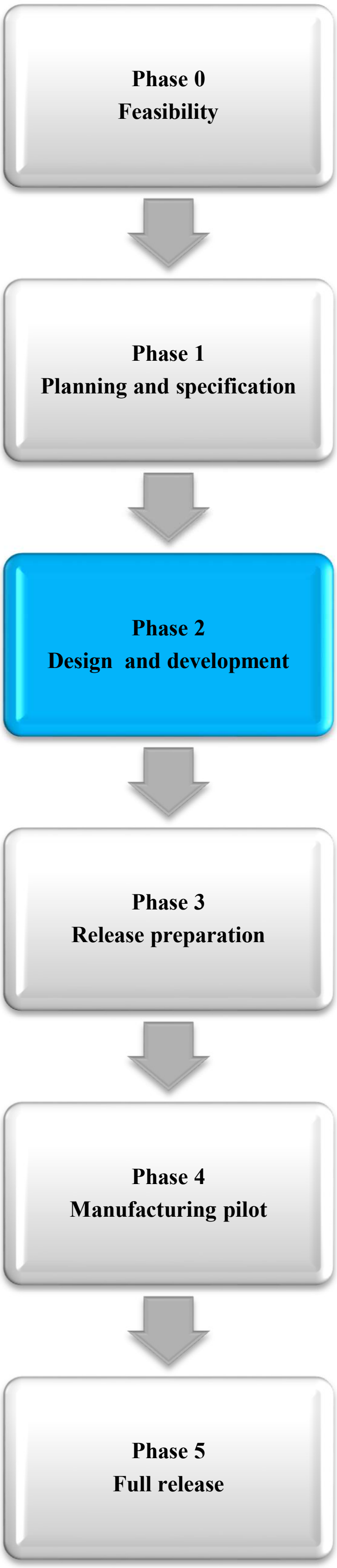
- Demonstration of the Technological Readiness Level (TRL) via prototype and/or Engineering Check Sample (ECS)
- Qualification planning / development of supporting processes as needed
- Selection of Suppliers with qualifications plans on track
- Design of the manufacturing process

Main actors

- Technology (R&D)
- Product marketing
- Operations
    - Production management
    - Purchasing/supply chain management
- Manufacturing and assembly
- Suppliers

3DCE guidelines

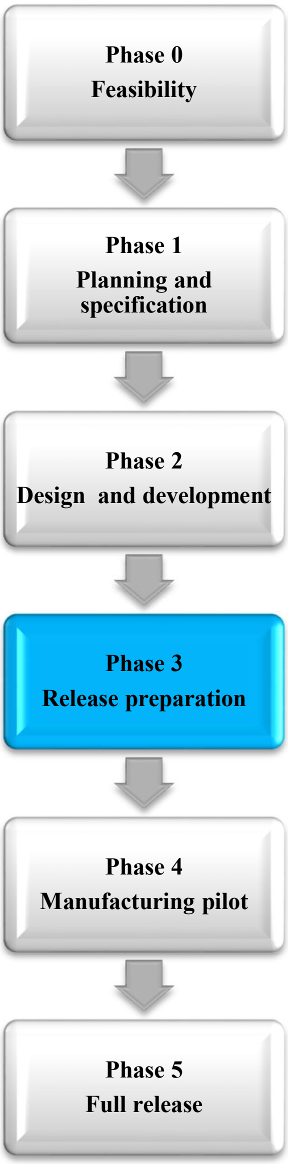
- Ensure the match between the electronic design and mechanical design of the product by effective coordination among mechanical and electronical design teams
- Perform virtual modelling of the product design by the manufacturing design team.
- Analyse virtual models in several iterations order to satisfy the requirements of the production design team (Size of the machines, number of robots, technology, costs, etc.)
- As the design converges and becomes clearer, the involved actors should stay committed to the finalized set of solutions in order for the others to be able to trust the communicated information
- Involve the supply chain design actors in the virtual modelling procedure in order to ensure the satisfaction of supply chain requirements.
- Coordinate different production groups (HV, LV, Panels and Systems) in order to choose the solution that is adaptable to all the section.
- Ensure that the product assemblers can test the product in advance and provide feedback, thus providing opportunities for to adjust the design based on the feedbacks



3DCE guidelines - continued

- Evaluate different strategies for packaging and transportation of plastic parts from sub-suppliers in order to design the right geometry of parts and ensure correct design for oriented transport.
- Facilitate the communication between the design team and the suppliers to incorporate the technical feedback regarding the manufacturability and assembly of the product and its parts. In case of change of suppliers under the way, ensure that the technical feedback will be provided to the design team, through other actors with "know-how".
- Ensure that the pace of development for electronic and mechanic parts are consistent to avoid components which are incompatible
- Match the product with its respective customer to avoid selling over qualified products to customers which don't require it. For example; selling a product which is designed for application in the offshore sector and to private individuals.
- Involve the software designer early in the phase.
- Perform root-cause analysis for product failures to fix mistakes and to add new functionalities by the product design team.
- Investigate possible customer delighters to gain competitive advantage over the competitors.
- Carry out simulation analysis for internal value chain optimization. Design the value chain of the product with decoupling points. Decide where the buffer stocks of material and inputs should be located in the supply chain.
- Design the appropriate control policies to ensure the material availability (e.g. Re-Order-Point system).
- Consider integration of RFID chip in developed product in order to facilitate installation and logistics (real-time tracking) and improve the accuracy of placement of correct parts at correct places.
- Calculate safety stock levels of ingoing components.
- Perform rapid prototypes; the prototypes are improved based on the results acquired from the prototypes developed in the previous stage.
- Test easy assemble-ability of the product by the service department (Internal function in PDC)

5.4 Phase 3. Release preparation



Goal

Optimize the manufacturability of the product (via Manufacturing Check Sample (MCS) and field trial results)

Activities

- Complete product testing (except for pilot tests)
- Launch Plan / Sales Strategy
- Qualification of supporting processes as needed
- Demonstration of manufacturability (via Manufacturing Check Sample (MCS))
- Type approval according to regulations

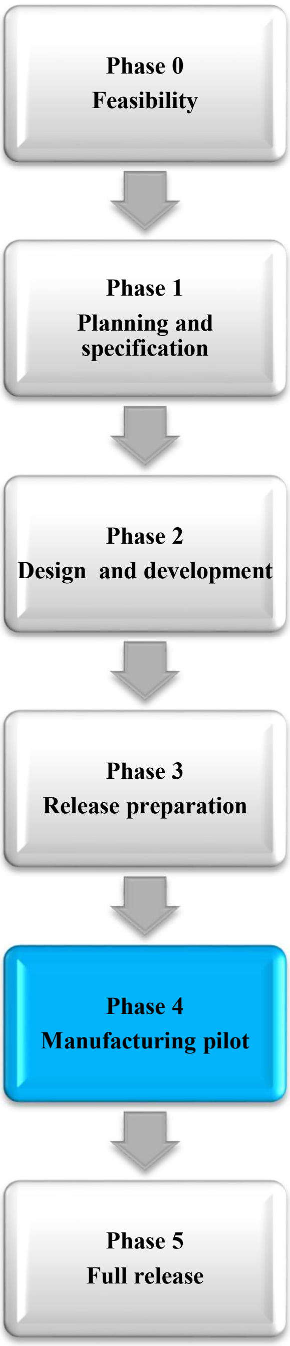
Main actors

- Technology (R&D)
- Operations
    - Production management
    - Purchasing/supply chain management
- Manufacturing and assembly
- Customers
- Sales

3DCE guidelines

- Design and control the information flow (documents, specifications, test procedures, certificates and standards)
- Evaluate the match between the requirements and the characteristics of the product to be manufactured
- Perform a *Sales and Operations Plan* for verifying and validating the new product, its marketing and high volume production process; this calls for the involvement of the marketing & sales and the production department.
- Should the product and variants be made to stock or made to order? Most manufacturing processes require buffer stocks. Supply chain costs will often be reduced by moving buffers upstream. The possible extent of moving stocks upstream depend on the resulting response time/lead time experienced by the customer.

5.5 Phase 4. Manufacturing pilot



Goal

Optimize the manufacturability of the product (via Pilot builds and field trial results)

Activities

- Evaluation of pilots
- Preparation for sales deployment
- Preparation for product release

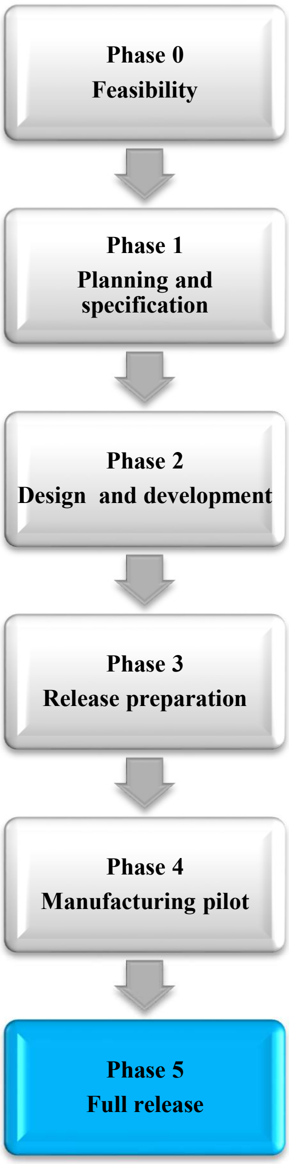
Main actors

- Technology (R&D)
- Operations
  - Production management
  - Purchasing/supply chain management
- Manufacturing and assembly
- Customers
- Sales

3DCE guidelines

- Final design validation of the product
- Evaluate the match between product requirements and product functions
- Evaluate the functionality of different product variants
- Ensure that all the technological risks are mitigated.
- Prove out the manufacturing processes and documentation
- Introduce the product to the market
- Ensure the justification of product variants to particular market segments. Variants increase supply chain costs significantly and increase complexity of supply.
- Analyse the potential for full scale automated production and possible production control system (Tracking of components throughout the manufacturing process). Once the control points identified, tag the products with real time identification technologies (e.g. RFID, barcode) for real time monitoring and control.
- Ensure that all the open actions are closed
- Ensure that the manufacturing process capability is acceptable
- Train the sales and technical support teams to prepare for the launch of the product
- Perform preparations for the first shipment of products

5.6 Phase 5. Full release



Goal

Secure the market while stabilizing the manufacturing processes.

Activities

- Release of final product
- Optimization of manufacturing processes
- Transition ownership of program
- Plan for product end-of-life

Main actors

- Operations
    - Purchasing/supply chain management
- Customers
- Manufacturing and assembly
- Sales

3DCE guidelines

- Facilitate the full scale operations, marketing and sales of the product.
- Develop a ramp-up plan in order for the production system to handle increase the order number from small to foreseen maximum number
- Develop a marketing plan
- Perform a sales and distribution planning
- Perform advertising and promotion planning
- Perform a review of the market performance to learn from the mistakes

Alongside the actions mentioned above it is important to perform a sound risk management process for new product development projects as well. In nowadays manufacturing the processes turn more complicated and faster. The pallet of possible solution is wide and decisions more sophisticated. Therefore here is extremely importance of new topics about identifying risks, managing risks and avoidance of risks. An example of evaluation of possible risks regarding the production of the new product is illustrated below:

Risk element	Consequence and probability	Risk response
Technological risk Requirements of the product from different technical disciplines (mechanical, optical, etc.) and operational entities (production, logistics, sales) will be contradictory The input and costs for achieving the necessary flexibility is too high and industrialization of the necessary technologies and methods is not reliable.	It takes longer time to start the production process. High probability Take longer time to set up the production system after the product design is developed. It's more cost demanding to produce new product variants. High probability	Structured and creative problem solving in multi-disciplined teams, continuous information sharing. Clear communication among partners. Early evaluation of technologies and methods.
Market risk The product will be produced by the competitors. The market for ew product not as large as expected.	We should Realize this anyway, however with a lower margin. Low probability The revenue reduces. Low probability	Focus on competitive power and reduction of time to market. The business case must be well founded.
Financial risk Project stop in /PDC	Large consequences for PDC's future. Low probability	Clear and reliable business case.
Organizational risk Different environments which have no earlier collaboration experience Involving all organizational partners early in the process, leading to changes might result in consequences	Ineffective cooperation Low probability Supplier change can lead to lost competence / knowledge	Defined roles and clear communication, good project management
Implementation risk Challenging to implement 3DCE in an industry which is used to sequential processes (waterfall method)	Delay in the project, increased costs Medium probability	Clear communication, good project management Organizational culture change

Figure 9 Example of Risk register for new product

The abovementioned actions to a great extent facilitate an effective iterative process by creation of a positive feedback loop and preventing re-work. This will eventually lead to achieving of the benefits of 3DCE which are:

- Reducing time to market
- Cost saving
- Optimal choice of components and material
- Faster response to customer needs
- Better access to vendor's knowledge

6 General advice and lessons learned

6.1 General advice

In the previous section, a list of specific actions that can contribute to facilitation of 3DCE within PDC and the possible responses to potential risks were presented. In this section we will elaborate on the general requirements for effective implementation of 3DCE from an organizational perspective. These elements are identified based on the experiences gained through Test Development project as well as co-running projects at RDA and PDC.

Involvement of top management and department leaders

The 3DCE model suggests that organizations should strive towards the alignment of product, process and supply chain design. It seems likely that usually one or more elements influence the proposed relationships among the core concepts of the 3DCE model. The attitudes of top management, including CEOs and managers responsible for operating divisions and subunits of organizations plays a key role in the success of this approach. This is due to the fact that the top managers' preferences, goals, interpersonal styles, resource allocation approaches, etc. can impact their choice of strategies.

3DCE is not simply a supply chain management tool; it's a management approach which involves the core actors within the organization (multi-functional teams) in the front end phase of the product development process in order to ensure rapid and effective response to customer demand while safeguarding the organizations own benefits. The main functions to be involved in case of NPD include: R&D, production management, sales and marketing, supply chain management and procurement management. Deep involvement from higher-level management should be ensured to improve coordination between departments and make timely tough decisions.

Wide information sharing within the organization

The success of NPD projects of high-cost, engineering-intensive, and customized development products is largely dependent on information sharing with both actors from customers regarding their specific requirements and actors within different functions within the organization. Project managers are at the heart of this process and plays an essential role in orchestrating the information sharing among various intra-organisational actors.

In fact, the project manager should through relationships with core actors orchestrate information sharing among other intra- or inter-organisational actors during the progression of an NPD project. This is a complex and dynamic process task due to the involvement of diverse functions from different organizations. The project manager's task is to identify the actors which are particularly important to coordinating the information sharing during the NPD process.

In order to fulfil this requirement there is a need for dynamic interface management and stakeholder management activities throughout the NPD life cycle. An effective stakeholder management process will aid project managers to develop appropriate strategies for effectively engaging different stakeholders in project decisions and execution. The stakeholder management plan involved the stages illustrated in the following figure.

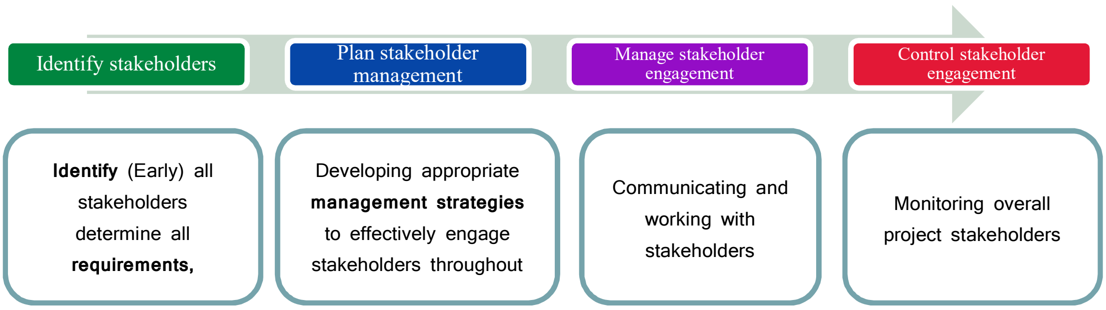


Figure 10 Stakeholder management process

Resource allocation and collaboration on multiple levels

Availability and allocation of the right resources with the right skills is one of the most important success factors for NPD projects. The most common problem in many NPD projects is "many projects for the resources". A lack of focus and inadequate resources is known as the number one weakness in businesses' new product development efforts. Every manager wants to load the resource pool at maximum "efficiency" with key personnel multitasking across several projects, ultimately slowing every development. An effective resource allocation process prevents system overload. Front-loading resources can be an effective solution to this challenge. Phased development processes emphasize incrementally adding resources as each phase concludes. Increasing resources at the beginning, however, can increase speed. Extra resources are added late in a project. That can actually slow the project more than it helps. In order to achieve an effective resource allocation process, 3DCE should be formalized by integrating it in a stage gate process.

Structural mechanisms such as cross-functional teams can also provide significant increases in NPD-related intern functional integration. In addition there is an absolute need for collaboration among resources as well. However a high level of collaboration depends on participants who contribute an openness to change, a willingness to cooperate, and a high level of trust. A number of organizational factors also affect this level of collaboration e.g. the priority that senior management gives to NPD and the level of autonomy afforded to participants in the NPD process.

An effective approach for ensuring collaboration and integration within an NPD project is to assure high levels of integration via teamwork and at the same time seek new ways of linking people and functional groups that creates synergies, utilize existing talent to their fullest potential and harness people's creativity and learning to accelerate the NPD process. This can be done through for example naming someone in all three disciplines to take responsibility for collaboration/parallel development.

Also training can improve effectiveness of the resources. This can be achieved by organizing a custom 'DFA[4]/Manufacturing for designers' course for designers at the beginning of a project focusing on what features in a product make save time and money during production. Similarly, 'Logistics for designers' course at the beginning of a project can be a relevant idea.

[4] Design for Assembly

Effective communication in cross-functional teams

Most studies point out that communication is the main parameter for a successful 3DCE and is at the heart of methods like Toyota set-based and design for lean manufacturing. In cross-functional teams, the members are brought from different department and work together only for a period of time until the project goal is achieved. The team members have usually different backgrounds, objectives, authorities, responsibilities, and even geographical locations. Therefore, the team participants are likely to have dissimilar points of view on one issue and relatively different “languages”. In PDC, the operations department works with the sales and marketing department performs market research and their aim is the market and how to satisfy customers. On the other hand, R&D department is responsible for designing the products and works with technical issues such as how to make the product’s function improve or more innovative. However, R&D needs to follow the project scope given by operations department.

In addition there is an accurate need for active communication with the supply chain functions such as purchasing, warehousing, transportation, etc. Therefore it is evident that specialties, objectives, responsibilities, and authorities of these divisions are diverse. Hence, functional diversity is a potential cause of communication challenge. The communication within the team is given in the NPD process mostly through meetings and milestones serving as common objectives. Typical examples of information that should be communicated would be decisions, status, planned activities within each stage, challenges, problems, suggestions for improvements should be shared among the project team. There are several ways to do this. The stage gate structure is meant to enforce such communication when passing a gate. At that point critical information must be collected, evaluated, and when the gate has been passed it is available for the next phase.

Within a stage meetings are of course good ways of passing such information. However, the process might be limited to a few number of meetings causing lack of transference of critical information among the teams. For example, frequent Design for Automated Assembly (DFAA) reviews should be organized. These meetings are low cost and ensure to avoid most manufacturability issues. Hence, communication among team members should be encouraged from the beginning of the project. Moreover, it is important to have a good *communication plan* in the new product strategy stage. An example of a communication plan is presented in the figure below.

What information	Target audience	When	Method of communication	Provider
Meeting on status report	Product manager, production manager R&D manager, Supply chain manager	weekly	Meeting	Product manager
NPD marketing plan	Product manager, production manager	2 weeks after project commenced	Meeting	Marketing manager

	R&D manager, Supply chain manager, Marketing manager			
Deliverables tracking plan	All project team members	Weekly	Meeting, presentation	New product development team

Figure 11Example of a communication plan for an NPD project

6.2 Lessons learned

The guidelines above have been developed based on a set concrete product development work, interviews, workshops, document analysis and meetings with PDC and other partners. Analysing the process we found that the main problems identified within the project were:

1. Slow decision making processes (due to lack of effective communication)
2. Lack of enough involvement of individuals from each of the three disciplines
3. Too much Focus on the costs from the top management side
4. Lack of clear specifications of the product in the early phase

We have addressed these issues already, but we will repeat some of the key issues here.

The first is that all involved in 3DCE work must understand what 3DCE work is, and how it should be supported by the Stage gate model. The essence of 3DCE lies in iterative processes where decisions on desired results are arrived by repeating rounds of analysis or a cycle of operations. The objective is to bring the desired decision or result closer to discovery with each iteration. The iterative process can be used where the decision is not easily revocable or where the consequences of revocation could be costly.

However, constant iterations can also be costly and the process must stop at some time. Stopping points is defined in the form of stage gates in a stage gate model. At each gate work is summarised and the iteration stops when the gates is passed. A new stage opens for a new iterative process, with new goals, activities, actors and plans. Employing the 3DCE in a state gate model we get a series of iterative improvements where each iteration is closed by the stage gate. We also get a set of decision points as gates, where information is brought together, synthesised, organised and evaluated by the actors. This information and these decisions now form the new starting point for the next iterations. Risk is better managed.

The second key lesson is the need for involvement, responsibility and communication throughout the project. 3DCE involves three different disciplines and if the iterative process should work each discipline must allocate a person with responsibility for the process, in order to serve as a contact point and to ensure that the needs/involvement of this discipline is taken into account in the process. It is important to allocate the right people to the right type of project based on their experience and competence.

Finally, some cross training of personnel in the other disciplines can be valuable, like organizing a custom 'DFA[5]/Manufacturing for designers' or 'Logistics for designers' course at the beginning of a project can be a relevant idea.

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[5] Design for Assembly

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