CONCURRENT ENGINEERING: ROAD TO THE FUTURE

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ABSTRACT

This paper presents a brief overview of the various aspects of concurrent engineering. The basic elements of the Concurrent Engineering practice in today's competitive world have been presented with special emphasis on its main advantages and constraints. Finally, a case study elucidating the successful implementation of this practice at Denver Works is discussed.

I. Introduction

A widely accepted definition of Concurrent Engineering (CE) is "a systematic to integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the product developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements." A more correct interpretation of this CE definition includes the up-front conceptual product definition processes as part of "design". This definition applies to services, software, or manufactured products. All associated documentation, such as customer training materials, needs to be considered as part of "products".

CE focuses on the product as used by the customer. This approach requires striking a balance among functional disciplines. In CE, cross-functional teams are formed to provide a forum in which the individual expertise of its members melds to create and deliver a more competitive product. The CE team has considerable power to affect the success or failure of a product when it operates as a single entity, and the team has complete end-to-end control over the product life cycle. The unified cross-functional team uses its knowledge to assure that all considerations are incorporated into a product early in its development. This includes performance and functionality, as well as Design for X (DFX) considerations. Real time collaborations on these considerations can improve product quality – in contrast to sequential, de-coupled reviews.

II. Why didn't the sequential process continue to work?

The shift from sequential design process to concurrent engineering approach was primarily caused by three primary factors.

Rapid pace of technology

Technology was advancing at an ever-increasing pace. Some companies were able to take advantage of the new technologies and convert them into products gaining market share. This put tremendous competitive pressure inside the companies that remained behind. Design groups were being forced by these business pressures to develop products in record time and to provide competitive advantage to regain the lost market position. Once companies fell behind in the technology curve, it was very difficult and at times impossible to catch up. Time-to-market, which is the term used to identify the time between the initial idea to the time the first customer product is shipped, became the competitive strategy and rallying point for many companies. The luxury of long product and process development cycles was doomed.

Forced design cycle compression

As engineers became pressurized to develop products more quickly, manufacturing input or marketing input became low on the priority list. Product development was all engineers had time to do. They became focussed on the management-dictated requirements and specifications. Product inputs from other functions that might cause a slip in the design schedule were often ignored. Thus, as marketers learned more about the customers' needs and expectations, and manufacturing engineers learned more about the cost to produce the product and manufacturability issues, few of their recommendations could be incorporated into the design under development. Any accepted recommendations were incorporated only if they did not have an impact on the overall product development schedule.

As a result major mistakes were made. Products missed their target in the marketplace. Designs were unproductive or had much higher manufacturing costs than expected. The finished designs were often delivered significantly later than planned or expected. This was due to the development cycle to correct design deficiencies or inadequacies. Thus, companies learned that simply hurrying the design process was not the answer to overall time reduction in the product development.

Emerging information technology and methodologies

New design technologies were emerging to help the development process. The emergence of workstations and personal computers allowed computer-aided design (CAD) and computer-aided engineering (CAE) to become significantly more cost effective and more widely used. As a result, CAD and CAE capabilities were improved. CAD was not only a way to eliminate the tedious tasks of accurate drawings but it also provided new capability such as multiple views, 3-D solid object views, electronic assembly and others. CAE tools, especially simulation, were being developed to help analyze products in a more technically robust and detailed way.

Electronic communications emerged as a way to speed up the process. By making the communications electronically written, and logged through electronic mail, individuals could be held accountable for the accuracy and dependability of their input. Additionally, the fundamentals of project management could be tracked more easily. Specifically, the time individuals took to respond, and the time taken to respond to action items, once difficult to pin down after the fact, could now be tracked through the logging of messages in electronic mail routines.

Additionally, several new structured methodologies emerged which resulted in better ways to understand and predict the product functionality, cost or market acceptance. As examples, material and assembly costs were minimized using Design for Manufacturability (DFM) techniques. Quality Function Development (QFD) emerged as a better way for the marketing, manufacturing and engineering functions to assess and agree on key product features.

Thus, the information technology and the structured methodology foundation required to reshape the development process into a concurrent engineering process were emerging.

Coupled with these three major factors were other organizational and behavioral factors that contributed to the emergence of concurrent engineering.

III. The basic elements of Concurrent Engineering

The combination of six fundamental elements of CE characterizes and differentiates it from traditional product development. The six elements are cross-functional teams, concurrent product realization process (PRP) activities, incremental sharing and use of information, integrated project management, early and continual supplier involvement, and early and continual customer focus.

Cross-functional teams

CFTs have representation from many or all of the functional areas across the entire PRP for manufactured, software, and service products. This representation includes marketing, systems engineering, design, manufacturing, purchasing, field services, and even customers and suppliers.

Concurrent PRP activities

PRP activities are executed in parallel, with some or all of the activities occurring simultaneously, rather than sequentially. Examples include:

- Performing simultaneous product and assembly process design, rather than waiting for a fully completed design.
- Developing part of a technical prospectus when feature descriptions are available from the market service description (MSD).

Incremental Information Sharing and Use

In each of the above examples, information is shared incrementally, as soon as it becomes available, which allows immediate feedback. This is in sharp contrast to waiting for a transfer of a complete set of information in the classic “over-the-wall” mode. Examples of incremental sharing include:

- Performing material planning and procurement activities, using a subset of the material needed as specified in the early design information.

- Determining the technical feasibility, using a subset of the customer requirements extracted from market research information.

Integrated Project Management (IPM)

When a CE approach is taken, project management changes in four major ways:

1. Project management is integrated to encompass and-to-end activities involved in the PRP. Milestones, and the responsibility for meeting them, are shared by all members of the concurrent engineering team.
2. Tracking mid-activity status becomes critical, since incremental information sharing can trigger other activities.
3. Target dates and knowledge about the PRP's information flow are used to prioritize work in each functional area.
4. Greater emphasis is placed on change management, since concurrent activities place considerably more stress on the management of information.

Early and Continual Supplier Involvement

Involving selected suppliers early on enables the CFT to better understand the design to the suppliers' capabilities, take material off the critical path, and leverage the design capabilities of the suppliers.

Early and continual customer focus

CE focuses the team on customer needs by providing an opportunity to absorb and act on customer inputs. This ensures that design and test decisions, beyond high-level requirements, are made with the customers' viewpoints.

IV. Communication in a CE environment

A successful implementation of CE requires excellent communication between all elements throughout the PRP. This is essential because

- The use of CFTs is aimed at articulating and using knowledge from functions across the PRP.
- Concurrent PRP activities require real-time communication during simultaneous activities, and clear, unambiguous sharing of incremental information.
- IPM hinges on the communication of the status of activities, resource information, and priorities.
- Early involvement of customers and suppliers increases the frequency and quality of communications with them to accelerate and enhance the PRP.

V. Why use Concurrent Engineering?

Studies on many different implementations of CE have consistently indicated the substantial advantages of CE in bringing lower-cost, higher-quality products to market faster. The following chart shows the data comprehended from AT&T and other companies to elucidate the benefits of CE implementation.

CE Benefit	**Reduction/Improvement**
Time to market	30 – 60%
Product life cycle costs	15 - 50%
Engineering changes and rework	55 – 95%

Time to market is reduced through many CE mechanisms: activities are coordinated in parallel rather than sequentially; rework loops are much shorter; and with constant communication, the cross functional team and PRP are able to react to changes more quickly. Cost benefits are the result of lower-product costs, which CE reduces by forcing effective decision-making early in the PRP – where up to 90% of the life cycle costs are determined. Development costs are reduces due to shorter intervals, less rework, and lower costs for product changes.

A study on the cost of engineering changes found that the cost change increase by a factor of 10 through the phases of design, design checking, reviewing, pre-production, production, and finally, use in the field. The quality of products and services can be increased dramatically through a CE-based PRP, because the CFT is more creative and effective at realizing a product that satisfies customers' performance and function needs, as well as meeting DFX considerations – especially with early customer involvement.

VI. Systematic implementation of CE: An example

This section describes a systematic Business Unit (BU) level transformation to a CE paradigm thorough an example. The CE effort between Denver Works and its three major design laboratories began in 1988, when "concurrent engineering" was becoming more prominent in the engineering literature. Two of the design laboratories were part of one BU, Business Communication Systems (BCS), and one was part of another BU, General Business Systems (GBS). One lab was co-located with manufacturing, while the other two were at remote locations. All three labs introduced designs to a common manufacturer, the Denver Works. This was a relatively complex situation involving four organizations, two co-located and two remote. The steps that GBCS went through to achieve the transformation are discussed in detail.

Transformation steps

Adhering to a rigorous process-management method ensures that process improvements are driven by facts and not guesses. The following were the steps taken in the GBCS project.

1. Benchmark and establish performance targets.
2. Establish the structure for breakthrough improvements.
3. Characterize the current process.
4. Create the target process.
5. Verify all new processes.
6. Implement new processes across the entire set of product lines.
7. Measure the results and continuously improve.

Benchmark and establish performance targets

This step provides a clear imperative, or vision, for the project, based on a competitive reality. Benchmarks for design and the introduction of similar products showed that BCS and GBS products lagged behind best-in-class intervals of other companies by 30% or more. The team recognized that the reengineering process would be a multi-year effort and, therefore, set the breakthrough improvement target at a 40% improvement of their current performance. This target then became the rallying point for the entire effort. Although aggressive, this goal, in the absence of any knowledge on how to achieve it, forced the team to entertain some radical new thoughts, instead of employing the usual bromide of "just doing everything a little faster".

Breakthrough Improvement

Once the team established a benchmark that indicated the need for a major technological shift in how things get done, often called a "breakthrough improvement", mastering the resources to achieve the breakthrough became the critical need. A careful analysis of the driving factors influencing the project structure preceded any decisions on the structure. Three factors were:

1. Success required an unprecedented level of partnership between design and manufacturing.
2. The basic organization of the labs and manufacturing could not be altered.
3. Breakthrough improvement would require support of managers at least two levels above the working level, and preferably higher.

The project structure resulting from these requirements featured three groups:

Steering committee: Mid level managers from manufacturing and design organizations met periodically to give and receive feedback on the progress of the reengineering effort.

Project office: An engineering manager from the Denver Works teamed up with an operations analysis supervisor from the internal consulting organization, Quality, Engineering, Software, and Technologies (QUEST), to co-manage the project on a day-to-day basis.

Core team: Engineers and analysts from the participating organizations worked under the guidance of the project office, and with the support of the steering committee, to complete the remaining steps.

Most core team members became full-time participants, even though this effort required the inconvenience of extensive travel for some individuals.

Characterize current process

The team gained intimate knowledge about the current process and its variations to prepare for the next step. This step also afforded the team the opportunity to build personal working relationships, understanding, and support among the various subject-matter experts across the PRP.

The core team characterized the PRP within the four organizations to gain insight into all the PRP activities, with a special focus on activities that contributed to the product – introduction interval. Flowcharting techniques and root-cause analysis were used extensively to accomplish this. Figure1 provides a high level view of the PRP before reengineering it with CE.

The team identified and quantified the following root causes for long product-introduction intervals:

Sequential design and manufacturing: Figure 1 shows that the design and manufacturing activities were performed sequentially. Design transfer triggered both production activities and manufacturing-enabling activities, such as creating programs for assembly equipment, documenting assembly instructions for production operators, establishing bill of materials, and the creation of test programs. Procurement activities started so late in the PRP that material lead times were often on the critical path.

Focus on intermediate milestones: Intermediate milestones such as the design-transfer date, were a driver for design activities. The designers' performance was based on delivering a functional design by the scheduled transfer date. Additional time was then needed by manufacturing to compensate for a lack of consideration given to efficient production issues in the early stages of design. This resulted in long intervals that put the product at a competitive disadvantage.

Extensive queues without priority control: Using a critical path method (CPM), we found that of the time these activities took, 80% of the total represented time in a queue, mainly because of numerous handoffs and ambiguous prioritization. This finding proved that the real problem to quickly introducing a product or service was managerial, rather than technological. This meant we could accelerate the PRP, without increasing the resources needed, by reorganizing project tasks strategically.

Multiple, unsynchronized databases: We also learned that vast amounts of redundant data were maintained in the design and manufacturing environments. This meant that data needed to be synchronized, typically manually, before products could be manufactured. The result was a process that added significant time, labor, and errors to the PRP.

Create the target process

The team took its time and focussed its creative energies, and the insights gained from the previous step, to visualize the characteristics of the best process imaginable before subjecting it once again to reality. This approach provided team members with the freedom to think creatively, and helped them design a realistic plan. Three of the CE elements: CFTs, concurrency of PRP activities, and incremental information sharing and use, were used as fundamental principles in reengineering the PRP.

The objective of a 40% product introduction interval drove the team to be radically creative with reengineering ideas. The resulting process integrated design and manufacturing activities, eliminated the need for design transfer, and combined two project management functions into one, driven by a single effectivity date (the date the customer needed the product) that drives all PRP activities. Figure 2 represents a high-level view of the concurrency that has been implemented. For example, material-management personnel analyze, concurrently with design activities, the components for lead-time consideration, based on an effectivity date, design trade-offs, and risks associated with early procurement.

A new information system (IS), to support the CE process, became critical. The new system had to provide a common environment for information on both the product and manufacturing process, and make that information available to everyone in PRP.

In summary, the target process differed from traditional PRP practices in the following ways:

- Use of one end date, the effectivity date, to drive all PRP activities.
- Business needs, including time-to-market and costs, influence the design decisions – in contrast to product functionality as the primary driver.
- Design transfer does no more than trigger production activities, i.e., acquisition of long lead-time parts, since manufacturing-enabling tasks are performed concurrently with design activities.
- Material lead-time is removed from the critical path.
- DFM/DFT issues are addressed via the concurrency of manufacturing value-added activities, which reduces reliance on non-value added reviews.
- Design stabilizes rapidly through quick, incremental adjustments, not through the long and costly rework loops that are common in the traditional approach.

Verify new processes

The team selected a pilot project to validate the system and process requirements for the CE environment. The pilot's goal was, therefore, to test specific strategies and assumptions to ensure that the process considered all of the factors necessary to achieve the goal of a 40% interval reduction. The expectations from the pilot were two-fold:

- Significantly reduce the interval for introducing a new product to benefit the business, and
- Validate the strategies, IS requirements, and process flows before full-scale IS and training investments.

The trial project, which included cost reductions for circuit packs and their mechanical enclosures, verified that the CE concepts were valid for mechanical and electrical PRP activities.

The CFT included people from all functions that normally participate in product realization. The key difference were that all players were named at the start of the PRP, and the facilitator, knowledgeable in CE, worked with the team to coach them through the process. A mockup of the target information-management system was used to validate all the necessary data elements, and their relationships, were clearly defined for all to understand.

The pilot demonstrated the basic soundness of the principles, and resulted in a significant acceleration of the product introduction. In the traditional PRP, circuit pack realization took longer than mechanical enclosure realization. In the pilot, circuit-pack realization accelerated more than mechanical realization. The pilot also revealed that tooling intervals for plastic parts are not amenable to acceleration through the CE techniques used. Also, the mechanical enclosure became a major controlling factor, or gating item, in the pilot, and highlighted a need to give enclosures an early start in the target process. The pilot led directly to full-scale implementation, which incorporated lessons learnt from the pilot.

Implement across product line

As the CE environment was implemented across the BU's product lines, several issues were encountered.

Training took several forms during the implementation. A concept course introduced the CE concepts through lectures, game-playing, and videotaped interviews with early practitioners. Additional training, centered around the IS and the new processes, was developed and presented to specific members. Users found that tool training became more meaningful when placed in a context that focussed on the workflow, and how tools support it.

Part-time teams formed to document new *operating norms and procedures* for the various phases of the new PRP. The procedures helped take advantage of the knowledge of experienced people in an usable format. It also provided input on where IS needed to be more flexible to accommodate the real-time variations in the process. The timing and strategy of transforming organizations required extensive planning. The goal was to minimize, during extensive transition, the time interval any organization had to spend both under the old and new processes. Projects were begun in each of the design organizations as certain individuals in each of the functional organizations were dedicated to operating the new processes. Additional people were brought on board as the momentum switched to the new processes.

An *information systems* solution needed to be deployed to support full-scale implementation of CE. A team was formed with the charter of characterizing and recommending an appropriate solution. Three candidate solutions existed at that time:

- Expanding local software platforms
- Adopting an outside IS solution
- Using a software system developed at Bell-Labs called "FOCUS-Prime".

A business case assessing the risk, cost and timeliness showed that augmenting FOCUS-Prime to fit the target process best met the selection criteria.

The *core team* designed the IS to enforce a common set of concepts necessary for interval reduction, while trying to accommodate variations among users on the specific processes to follow. Project teams formed from designers and manufacturing engineers were encouraged to decide their own detailed operating practices, in alignment with the overarching concepts, to empower them to use their creativity in refining the basic processes. This approach required flexibility in the IS, and added complexity in its development and in training.

The *project structure* also changed to support full-scale deployment, maintenance and support. An implementation team was added to partner with the core team. The implementation team contained people from various functional organizations. They were given in-depth training on the CE concepts and acted as facilitators as the projects adopted CE. The implementers joined the CFTs during the product design and introduction, and acted as advocates for those teams when they returned to the core team to report progress and problems. The core team then responded by changing the CE processes to meet the operational realities.

Measure results and improve

Results are given below for both a single-product CE implementation and a BU-wide CE implementation in GBCS. While a normal GBCS development took from 18-30 months, the development of the 408 MLX unit completed the project in 11 months. The result was due to their clear team objectives, and their adherence to the six CE principles – especially the use of CFT with end-to-end ownership. They went from three printed-board design cycles to just one, matching the benchmark for best-in-class companies for this critical path activity. Their greater than 35% reduction in interval was attributable to their being accountable for the entire project, and concern for the overall success, rather than just doing their particular piece of job.

The wide scale systematic implementation of CE in GBCS showed similar results. It provided interval reduction results and productivity gains. Quantifiable quantities included:

- A 40% interval reduction from design through manufacturing ramp-up.
- Elimination of pilot shop operations, resulting in a 100% savings in the cost to introduce the hardware product.
- A 50% reduction in the rate by which new components are introduced.

Full deployment of the IS and the CE-based PRP took about one year. This period required work in training, enhancing the IS, and working through organizational friction created by the new operating model. At the end of this interval, most of the people who would be affected had experienced being on at least one CFT, and most functional areas were using the new mode of operation.

Projects took initiative to form cross-functional teams early in the design cycle. Some designers and manufacturing engineers adopted the combined role of physical designer and manufacturing engineer on their cross-functional teams, as stability in process norms and the IS emerged. A Critical element was clear ownership for ongoing project management and stuffing to support the maintenance and evolution of information systems and processes. A tem consisting of process users and core team members analyzed the business results and documented the results summarized above. Even before the process and IS were stable, the business results became evident and were meeting original expectations. Part of the continuous improvement strategy included assigning the core team a role in strategic planning. The team realized that product technologies would create the need to revisit the new process, periodically, to look for even better performance from the PRP.

VII. Barriers to Concurrent Engineering

Along the way one may encounter several barriers to implementing CE in an organization.

Commitment/Culture

Resistance centered around cultural differences and individual and organizational commitments are common.

Lack of commitment from engineers: The philosophy of optimizing the end-to-end effort, while de-optimizing local efforts can make it difficult for functionally-focussed high performers. There will be skeptics who defer joining in because they believe that this is only one more “initiative du jour”, which will soon pass and be replaced by another quality/process fad.

Middle management resistance: Middle managers are often caught between the lofty goals of the upper management and operational realities. Dealing with these competing perspectives is difficult, and appears to others, as resistance.

Up-front investment: The CE implementation effort will require resources from different functional areas, training investment, and perhaps outside help. These resources may be difficult to obtain, because it is difficult to “guarantee” specific results.

Training: Academia prepares students to be high individual performers, whereas CE requires high team performance.

Risk: There is a greater need for risk management. With many activities going on simultaneously in a CE environment, many checks and balances present in a sequential environment disappear.

Fear of empowerment: Some managers resist the loss of control that results when his subordinates become empowered. At the same time, some employees fear taking responsibilities for their actions, and may refuse to become empowered.

Short-term thinking: Short-term pressures, reward systems, and performance measures are all designed to elicit high performance from the scope of a process covered by measures.

Organization

Organizational issues might adversely affect the implementation of CE.

Structure: The structures of normal functional organizations cause the resulting reward structure to center around performance inside each functional organization. This causes employees to work for the good of the functional organization, rather than the good of a product.

Physical/Geographic separation: Where permanent co-location is not feasible, CE implementation is an even bigger challenge, because significant informal communication cannot occur.

Technology

Basic communications may also cause problems.

Infrastructure: A poor communication infrastructure will hamper the implementation of CE. While phones are ubiquitous, e-mail, video conferencing, and computer networking may not be well entrenched. IS and process infrastructure may also require further development to best support CE. While these are not required, this infrastructure helps make CE much easier to implement.

VIII. Conclusion

Today "world class" is more than a catchy phrase. It's quickly becoming the blueprint to survival in today's competitive global markets. Better quality products, developed in less time, and at lower costs, seem to be driving goal for any industry today. In such a scenario, few will argue the benefits of concurrent engineering, or dispute its inevitable acceptance as the wave of the future for new product development. As implementers have seized the opportunity to maximize their resources and synergize their companies to a level of effectiveness, many concurrent engineering stories have been well documented like the one case-study elaborated before.

Concurrent engineering is not necessarily synonymous with the integration of expensive tools and high-tech manufacturing technologies. It begins with integrating a new approach designed to help the organization design it right the first time, establishing internal communications, and ensuring that the resulting product is – from its outset – customer driven.

Last, but not the least, many companies suffer from the false impression that CE is meant for high-tech, big-budget giants, and is not practical for average manufacturers. This is, however, far from the truth, and results from failure to understand the true essence of concurrent engineering practice. To put in the words of James Sherlock, vice-president of Manta Corp., (a company located in Milford, Ohio, that has helped many of today's computer-aided engineering tools and practices) "Concurrent Engineering isn't about high-tech products and technologies. It involves taking a serious look at the organization, scrutinizing processes and policies, and rethinking and reengineering the way, things have always been done."

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X. Figures

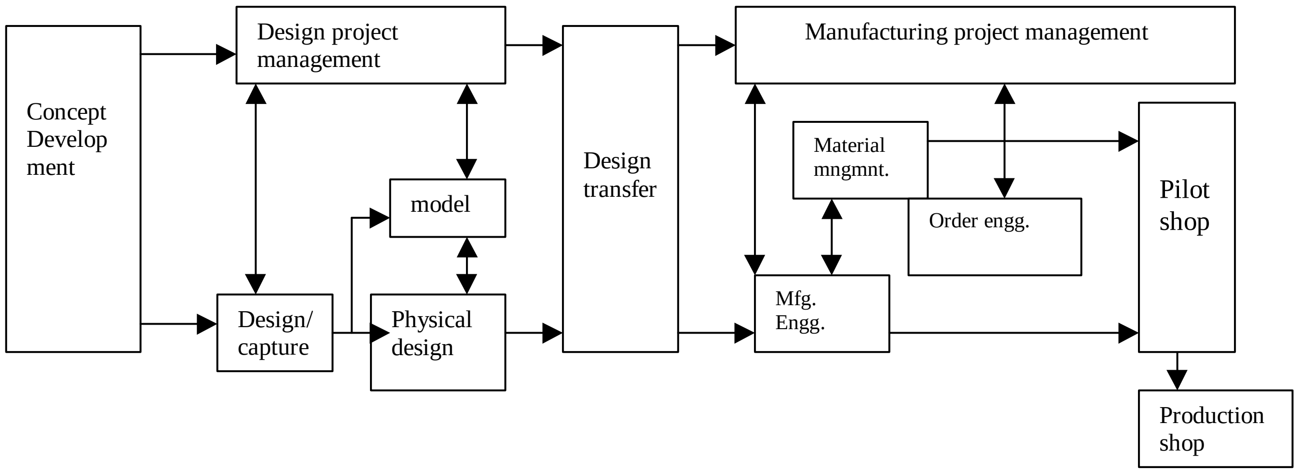

Fig. 1 : When design and manufacturing activities are performed sequentially, design transfer triggers both production activities and manufacturing-enabling activities, such as creating programs for assembly equipment, documenting assembly instructions for production operators, establishing bill of materials, and the creation of test programs. Procurement activities start so late in the product

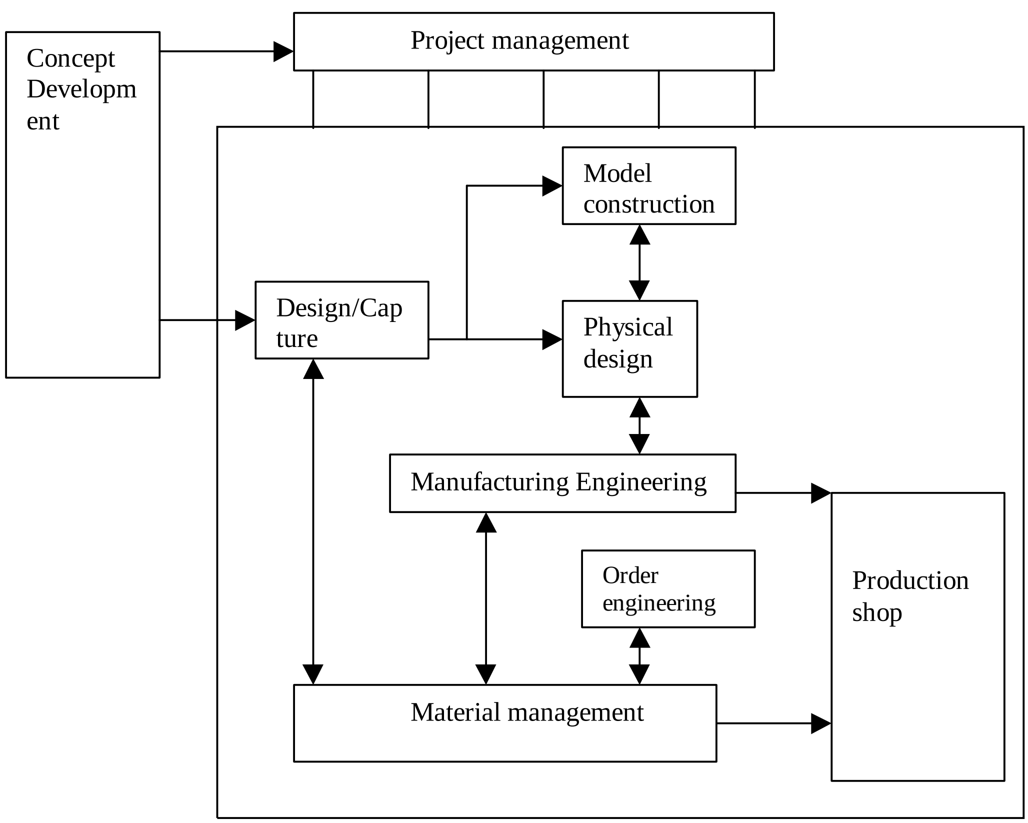

Fig. 2: With concurrent engineering, a concurrent flow of activities replaces the sequential flow. For example, material management personnel analyze, concurrently with design activities, the components for lead time consideration, based on an effectivity date, design trade-offs, and risks associated with early procurement.