POLITECNICO DI TORINO

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Methodologies for Product Development Excellence

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Abstract

In this thesis, a modern and innovative methodology and specifically with EPM Cost Deployment, a vital pillar of the World Class Engineering program proposed by FCA, is presented. After presenting a Literature review on the topics of Product Development, Automotive Product Development and Toyota Product Development System (TPDS), the work introduces the methodological framework of World Class Engineering and gives focus on the EPM Cost Deployment. EPM Cost Deployment is one of the best tools to identify waste and losses in the product development project and minimize or eliminate related cost. It is structured in seven steps. The identification of waste and losses in product development and detection of where they take place are the first two steps. Then, causal losses and resultant losses are separated and related in step three. Next, in step four, the identified waste and losses are translated into costs. In step five, responsible departments and processes are determined, and proper methods and tools are chosen to attack the identified waste and losses. After that, the amount of possible savings and related time, costs and resources consumed are estimated in step six. The last step is to evaluate the achieved results and follow-up to the next run. A case study taken from the application of the EPM Cost Deployment within FCA is presented.

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Chapter 1 – Introduction

The world economy has changed profoundly due to the effect brought by the current globalization. How to seize the opportunities and deal with the challenges to intensify the competitive advantage is the typical problem companies are facing. Nowadays, successful companies have one thing in common: they share a passion for creating value for the customer and in the meantime, gaining profit for the company. Given the importance of competitiveness, companies have tried out to eliminate waste, reduce time-to-market and costs in New Product Development (NPD). Santos et al. argued that one of the differentials of the companies are the early launch of the products and ability to develop them, with the objectives to meet the growing customers' needs and expectations. The product lifecycle is getting shorter, which encourages the continued flow of new product development projects in the industry (Santos, Loures, Piechnicki, & Canciglieri, 2017). NPD is among the essential processes for success, survival, and renewal of organizations, particularly for companies in either fast-paced or competitive markets (Brown & Eisenhardt, 1995). Similarly, Hoppmann et al. claimed that the impact on cost, quality, and manufacturing lead-time is usually much more significant in the phase of product development than during manufacturing (Hoppmann, Rebentisch, Dombrowski, & Zahn, 2011). In other words, successful companies are those able to launch desirable products at a faster rate than their competitors (Machado, 2013, July).

Considering the world automotive market, the ongoing competitive pressure due to industry overcapacity and increasingly sophisticated consumer tastes will likely to continue, which brings more challenges to the NPD. The global automotive industry is at—or at least rapidly nearing—a major crossroad that could determine its long-term trajectory (Ferraris, et al., October, 2017). The published article written by S&P Global Ratings analysts also argued that the accelerating technological transformation and changing consumer tastes and demands, which are likely to result ultimately in an industry that bears little resemblance to what it was just a decade or two ago (Ferraris, et al., October, 2017). The automotive business shows its double-sided complexity both in technical and customer relationship. The integration of many disciplines starting with materials science and the use of intelligent materials, electronics, mechatronics, and some other aspects contributes to the technical complexity. Due to the increasing competition of the market scenario, how to obtain, to understand and to accurately discriminate the right information that will drive product and process development, product styling and product marketing, results in the customer relationship complexity. Also, the time constraint during automotive product development also has a considerable impact on the company competitiveness.

This thesis aims to present establishment of the basic model of World Class Engineering (WCE) for the product development process in the automotive industry to meet the quality, cost, and delivery time target of the product.

The chapter is organized as follows: in Chapter 2 an introduction to Product Development, Automotive Product Development, and a brief literature review are presented; in Chapter 3 a benchmark analysis of Toyota Product Development System (TPDS) is described; Chapter 4 describes mission, principles, and frameworks of WCE, and in Chapter 5 a real case study in the automotive company focused on the specific

Early Product Management (EPM) Cost Deployment Pillar of WCE is presented. To conclude, results and conclusions are provided.

Chapter 2 – Literature Review

2.1 Product Development Introduction

Product development also called new product management, is a series of steps that includes the conceptualization, design, development, and marketing of newly created or newly rebranded goods or services (Rouse, 2016). Product development can also be defined as the overall process of strategy, organization, concept generation, product and marketing plan creation and evaluation, and commercialization of a new product (Product Development Definition - Entrepreneur Small Business Encyclopedia, 2018). Another definition given by BusinessDictionary.com website is the creation of products with new or different characteristics that offer new or additional benefits to the customer. Product development may involve modification of an existing product or its presentation, or formulation of an entirely new product that satisfies a newly defined customer want or market niche (Product Development, 2018).

Even though the definitions of product development may have a slight difference, the common sense they want to convey is that product development plays a crucial role in defining customer value. It determines the physical appearance of the product, identifies the materials to be used and, thus, mostly constraints the set of production processes that can be employed to manufacture the product (Hoppmann, Rebentisch, Dombrowski, & Zahn, 2011). The development of a product is full of uncertainty since it elaborates uncertain information, continuously modified from the beginning to the end of the process. However, the impact of these changes is not the same in any process phase; it is more evident during the development phase than production.

The objective of product development is to cultivate, maintain and increase a company's market share by satisfying a consumer demand (Rouse, 2016). It is not realistic to meet every customer's requirements, so having a bright idea of what customer the company will serve is the primary issue that needs to be solved at the very beginning of the product development process. How to serve this customer best is the subsequent issue which requires more creative thinking to offer value proposition of the company to the well-defined target market. Quantitative market research should be conducted at all phases of the design process, including before the product or service is conceived, while the product is being designed and after the product has been launched (Rouse, 2016). There are many uncertainties and challenges which companies must face throughout the product development process. A systematic, organized framework helps structure the actual product development and provides guidance about managing these uncertainties and challenges.

2.2 Product Development Frameworks

Delivering new products to the target market is a complicated process. The product development process typically consists of several activities which are parallel or overlapped. Every new product will pass through a series of stages/phases, including idea and concept generation among other aspects of design, as well as manufacturing and market launch. Given the importance of product development process, researchers and practitioners have proposed the product development frameworks in many different ways.

One of the best known of NPD models is the Booz, Allen, and Hamilton (BAH) Model, published in 1982, which underlies most other NPD systems that have been put forward (Booz, Allen, & Hamilton, 1982). This widely recognized model appears to represent the foundation of all the other models that have been developed afterward since it encompasses all the basic stages of models found in the literature. It is based on extensive surveys, in-depth interviews, and case studies and, as such, appears to be a reasonably good representation of prevailing practices in the industry (Bhuiyan, 2011). The seven stages of NPD in BAH model are shown in Figure 1.

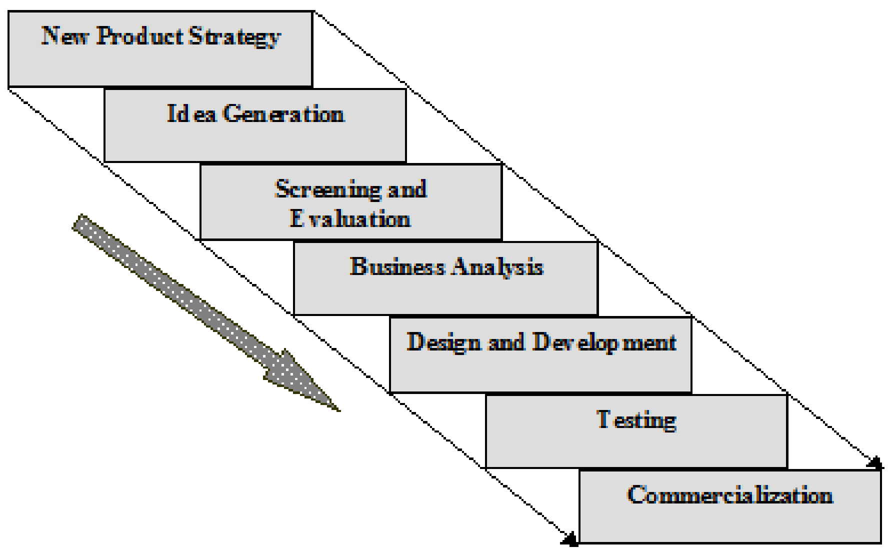


Figure 1. Seven Stages of BAH Model. Source: (Booz, Allen, & Hamilton, 1982)

The stages of the model are as follows (Bhuiyan, 2011):

Stage 1: New Product Strategy. Links the NPD process to company objectives and provides a focus for idea/concept generation and guidelines for establishing screening criteria.

Stage 2: Idea Generation. Searching for product ideas that meet company objectives.

Stage 3: Screening and Evaluation. Comprises of an initial analysis to determine which ideas are pertinent and merit more detailed study.

Stage 4: Business Analysis. Further evaluates the ideas by quantitative factors, such as profits, Return-on-investment (ROI), and sales volume.

Stage 5: Design and Development. Turns an idea on paper into a product that is demonstrable and producible.

Stage 6: Testing. Conducts commercial experiments necessary to verify earlier business judgments.

Stage 7: Commercialization. Launches products.

Booz, Allen, and Hamilton (1982) concluded that companies that have some formal NPD process are more likely to launch new products successfully and that their NPD process generally involves all the seven stages.

Another one of the most researched processes regarding new product development is the concept adopted by IDEO, a successful design and development firm in Palo Alto, California, which has brought the world the Apple mouse, the Palm handheld and hundreds of other cutting-edge products and services. The IDEO Process is made up of 5 steps (Moen, 2001), as shown in Figure 2:

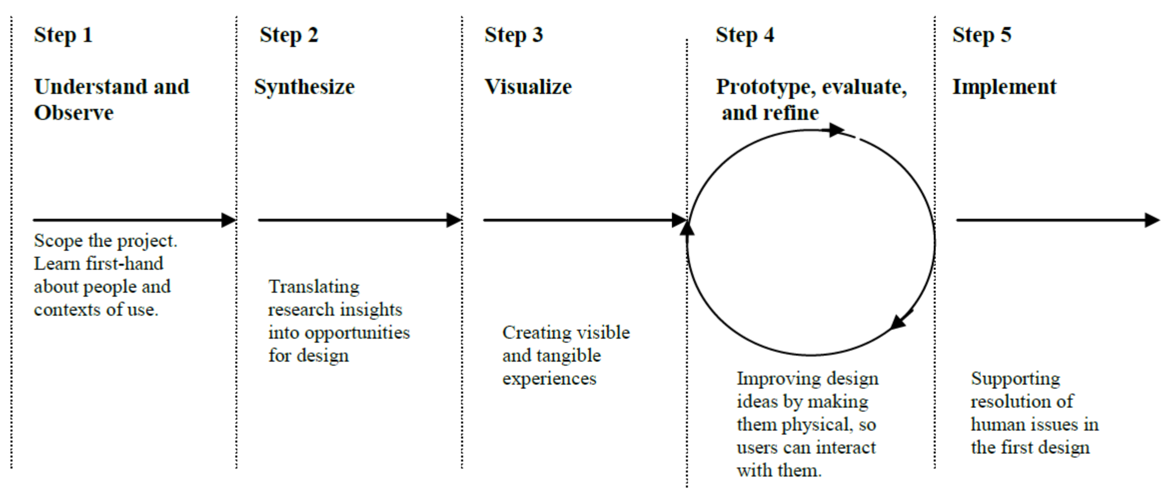


Figure 2. Five Steps of IDEO Process. Source: (Moen, 2001)

These steps are listed and defined below (Moen, 2001).

Step 1: Understand and observe. Understand the market, the client, the technology, and the perceived constraints on the problem. Observe real people in real-life situations find out what makes them tick, what confused them, likes and dislikes and potential needs not addressed by current products or services. Go to the source not the "experts" inside an organization. Inspiration comes from observation.

Step 2: Synthesize. All information from Step 1 is collected in the project room. This room becomes the key tool for translating the information into opportunities for design. Photographs, diagrams, and drawings are all mounted on the wall to prompt discussion and illustrate key insights. The room becomes a tool for sorting and recording the ideas that develop.

Step 3: Visualize. Be visual is a primary rule of IDEO brainstorming. Visualize new-to-the-world concepts and the customers who will use them.

Step 4: Prototype, evaluate, and refine. Prototypes shape the ideas. Prototyping is the shorthand of innovation.

Step 5: Implement. Design changes can be systemic or highly localized. Implementation is the most extended phase and most technically challenging.

In the 1980s, Robert G. Cooper proposed a famous Stage-Gate model which is both a conceptual and an operational model for moving a new product from idea to launch. It is a blueprint for managing the new product process to improve effectiveness and efficiency (Cooper, 1990). The overview of a stage-gate system is illustrated in Figure 3.

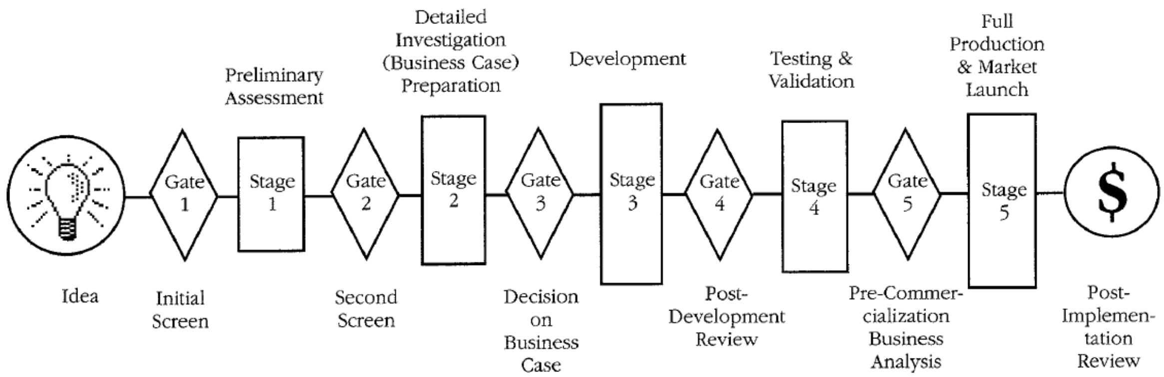


Figure 3. The Stage-Gate System. Source: (Cooper, 1990)

Robert G. Cooper also pointed out that the stage-gate systems involve from four to seven stages and gates, depending on the company or division. A typical model is shown in Figure 3. The various stages and gates are described below (Cooper, 1990).

Idea. The new product development process is initiated by a new product idea, which is submitted to Gate 1, Initial Screen.

Gate 1: Initial Screen. A preliminary but tentative commitment to the project. Focus the discussion and rank projects in this early screen.

Stage 1: Preliminary Assessment. Determine the project's technical and marketplace merits. It provides for the gathering of both market and technical information, and the project can be reevaluated more thoroughly at Gate 2.

Gate 2: Second Screen. This gate is mostly a repeat of Gate 1: The project is reevaluated but in the light of the new information obtained in Stage 1. If the decision is Go at this point, the project moves into a more massive spending stage.

Stage 2: Detailed Investigation (Business Case) Preparation. This is the final stage before product development. It is the stage that must verify the attractiveness of the project prior to heavy spending. The project must be clearly defined.

Gate 3: Decision on Business Case. This is the final gate before the Development Stage, the last point at which the project can be killed before entering heavy spending. Once past Gate 3, financial commitments are substantial. In effect, Gate 3 means "go to a heavy spend".

Stage 3: Development. It involves the development of the product and (concurrently) of the detailed test, marketing, and operations plans.

Gate 4: Post-Development Review. Check on the progress and the continued attractiveness of the product and project. Review and check development work to ensure that the work has been completed in a quality fashion. Revisit the economic question and approve the test or validation plans.

Stage 4: Testing & Validation. Test the entire viability of the project: the product itself; the production process; customer acceptance; and the economics of the project.

Gate 5: Pre-Commercialization Business Analysis. Open the door to full commercialization. It is the final point at which the project can be killed. This gate focuses on the quality of the activities in Stage 4 and their results. Financial projections are also considered. Finally, the operations and marketing plans are reviewed and approved for implementation in Stage 5.

Stage 5: Full Production & Market Launch. The marketing launch plan and the operations plan implementation.

Post-Implementation Review. At some point following commercialization, the new product project must terminate. The product becomes a "regular product" in the firm’s line. The project and product’s performance is reviewed. Finally, a post-audit is carried out. This review marks the end of the project.

Rouse (2016) concluded the fuzzy front end (FFE) approach and the design thinking frameworks and then proposed a composite NPD framework for manufactured goods. There are eight essential components as shown in Figure 4.

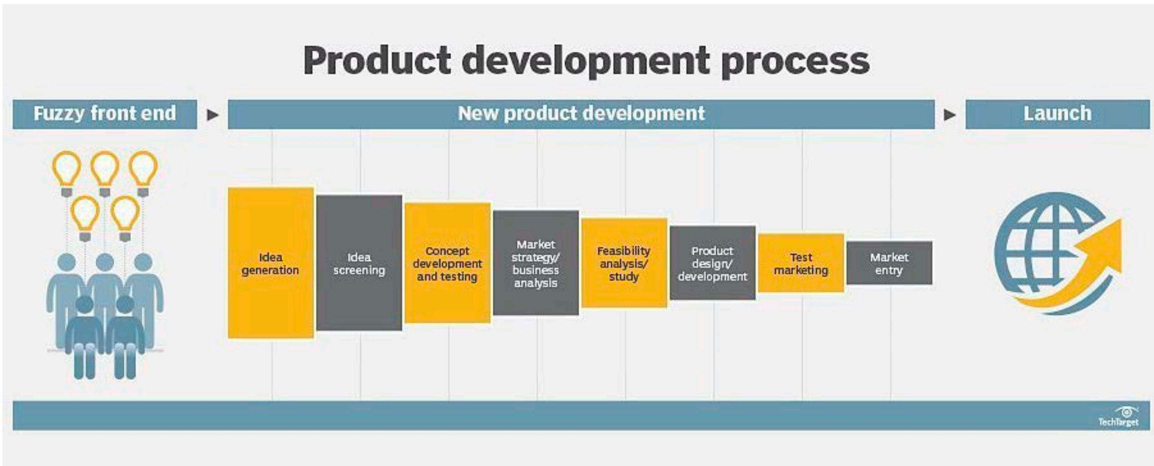


Figure 4. Eight Stages of New Product Development (NPD). Source: (Rouse, 2016)

Stage 1: Idea generation. Continuous seek for introducing new products to market, including modifying existing products.

Stage 2: Idea screening. Take the less attractive, infeasible, and unwanted product ideas out of the running.

Stage 3: Concept development and testing. The concept must be tested on a real customer base and adjusted according to the feedback.

Stage 4: Market strategy/business analysis. This stage is comprised of four P’s, which are product, price, promotion, and placement.

Stage 5: Feasibility analysis/study. It entails organizing private groups that will test a beta version, or prototype, of the product, then evaluates the experience in a test panel. Determine whether the product in development has the potential to be profitable, attainable, and viable for the company.

Stage 6: Product technical design/Product development. Integrate the results from Stage 5 into the product. This stage consists of turning the product into a workable market offering; deciding the product technicalities; and organizing departments in the company.

Stage 7: Test marketing, or market testing. Validate the entire concept – from a marketing angle and message to packaging to advertising to distribution. Vet the reception of the product before a full go-to-market investment is made.

Stage 8: Market entry/commercialization. Introduce the product to the target market. Use all the information obtained throughout the previous seven stages to realize commercialization.

The product development frameworks proposed by the researchers in the past help structure the actual product development. The framework may vary according to different kinds of products. The product development process is always evolving and changing adapting to the real situation. For those complex products, especially for the automotive vehicles, the product development process can be likewise complicated. The automotive product development process will be illustrated in the following section.

2.3 Automotive Product Development

In the automotive industry, the products produced are highly complex engineered products. The NPD process can be somewhat complicated considering management and coordination of different departments, personnel, and resources. The process for managing automotive products is much slower than that deployed for many types of consumer goods. The product development process has progressively become much more than the design phase, through the integration of many activities that in the past were outside its scope, such the market analysis, the benchmarking of competitors, the identification of target customers. It aims to plan the whole product life cycle, as much as possible according to customer expectations. The product development process drives most company performances, such as product quality, customer satisfaction, operational flexibility and development cost and time. In the past, the time has been perceived just as a constraint to the design phase, so essential to be accomplished even if product performances targets are only partially achieved; nowadays time is instead a target since it is a relevant source of competitive advantage, especially for automotive companies.

A possible theoretical subdivision of the product development process into its main phases is the following:

1. **“Concept generation and development” phase**

Starting from market future needs, available technologies and other strategic constraints, several product alternatives are hypothesized and ranked, and one or few of them are selected to be further developed and tested. In the automotive field, the concept is a description of the shape (and of the body type) and the expected functions and distinctive characteristics of the new product, including preliminary specifications for the technical performances, targeted customers, preliminary economic assessment.

2. **“Product development and engineering” phase**

The product engineering translates the assumed market requirements into the technical specifications needed for the detailed design of the new product, including styling and layout definition, under defined cost and investments targets.

Main contents of this phase are:

- Definition of product architecture and its deployment into systems/subsystems/components
- Description of geometries, materials, tolerances
- Make or Buy choices
- CAD drawings realization
- Design and production of the components prototypes and their assembly into the first concept physical approximation (running prototypes)
- Execution of testing process (both at vehicle and component level) and iteration of the “design-prototype-test-modify” cycle until product validation is achieved

3. “Process development and engineering” phase

Process engineering translates the specific components design into the corresponding manufacturing processes, under defined investment targets.

Main contents of this phase are:

- Plant design (design of the materials flows and the layout of the production plant)
- Hardware design (design of production lines and tooling)
- Software design (for production planning and control)
- Work design (definition of the standard operative procedures)

4. “Pre-mass production and production ramp-up” phase

The product is manufactured by means of the definitive production system, that is typically specific for one product. The production rates are step by step increased till the planned performances and possible technological problems are verified and solved.

Chapter 3 – Learning from Toyota

3.1 Company Background

Toyota Motor Corporation has built and maintained a competitive edge in the global automotive industry for the past 60 years and became the top worldwide automobile manufacturer for the first time in 2008. The company and its nearly 600 subsidiary companies are involved in the production of automobiles, automobile parts, and commercial and industrial vehicles (Toyota Motor Corporation, 2018). Besides high profitability in manufacturing and marketing, Toyota excels regarding new product development with outstanding lead-user times, short product cycles, high quality, and technical innovations (Fuchs, 2007). As of 2016, Toyota was the world's largest automotive manufacturer. Toyota was the world's first automobile manufacturer to produce more than 10 million vehicles per year which it has done since 2012 (Flynn, 2012).

One of the Toyota's management philosophy that has been widely researched is the term "Lean Manufacturing", which is based on the principle of Just-In-Time, building only the parts needed by the next process when they are required based on a pull system (Liker & Morgan, 2011). While the success of the company is not only due to the focus on manufacturing, the product development which is upstream of manufacturing also plays an important role. The Lean Product Development is an enabler to achieve the next level of lean manufacturing, and it also improves product development performance.

3.2 Toyota Product Development System (TPDS)

The Toyota Product Development System (TPDS) is not built in one day but evolves continuously with the development of the company. The product development cycle at Toyota started with intense market research and analysis of future trends in consumption and production. Then top managers defined their product strategies consists of quantitative performance and cost targets according to the market information. Subsequently, the new product development department took charge of designing the model.

Fuchs (2007) concluded that the early success of Toyota's new product development was due to the establishment of the so-called heavyweight project manager organization in 1953 and also spurred by the traditional Japanese employment system (Fuchs, 2007). A project manager was appointed for every single new car model and was given high authority over six functional division managers (design, engineering for body, chassis, power and electronics, and product evaluation and testing) and was grouped in the product planning division. During the 1960s Toyota had about ten project managers supervising five to six staff members in the product planning group and another 5 to 20 engineers from functional divisions working on their single development projects. This type of organization proved to be very efficient during the 1960s and 1970s. In 1972, Toyota's domestic production totaled over 10 million vehicles with cumulative exports almost reaching 4.5 million units, largely due to delivering new models at high quality and competitive prices every two to three years (Fuchs, 2007).

However, the rapid growth had significant effects on the new product development efficiency. The increasing degree of specialization and the growing complexity of project management resulted in fat designs and limited reusability of parts and technology for other models. The sharing of knowledge, basic components, and technologies between projects diminished slowly.

While the increasing shortfalls and cost in new product development were not seen as a significant problem by the company until the late 1980s. When sales dropped dramatically and prospects of a quick recovery deteriorated, the slowing productivity in new product development suddenly became a burden to future competitiveness. To tackle this problem, Toyota launched an internal initiative called the Future Project 21 (FP21) in 1990. The ultimate goal of FP21 was to identify issues existing in the product development organization and to make it fit for the twenty-first century (Nobeoka & Cusumano, 1995). The practical problem-solving is illustrated in Figure 5.

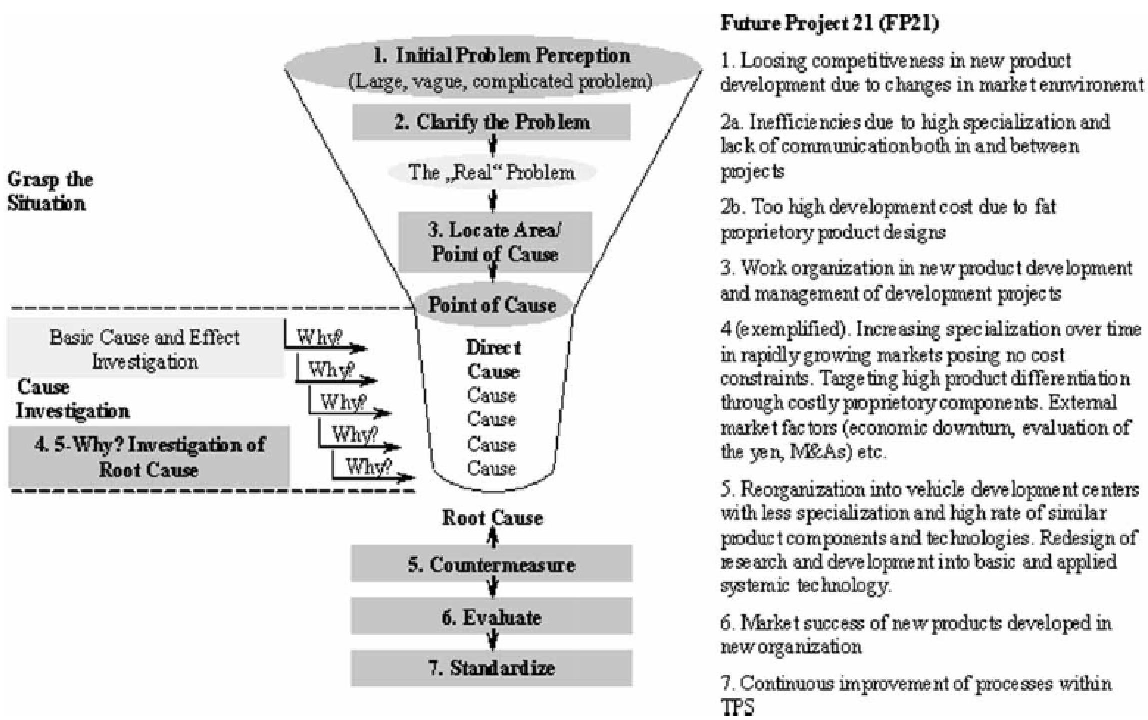


Figure 5. Seven-Step Problem-Solving Process in FP21. Source: (Fuchs, 2007)

In 1992, Toyota reorganized new product development and structured them into four centers: Center 1 was responsible for rear-wheel-drive platforms focusing on luxury and high-quality vehicles, Center 2 for front-wheel drive platforms and vehicles in the lower price segments, and Center 3 for utility and van vehicle platforms for recreational cars. Center 4 was installed to make better use of technology research and development (Fuchs, 2007). Systemic components such as air conditioning and supporting electronics were researched and developed to be applied to all car models in the near future. Engineers were transferred from the technical center to new product development center (Nobeoka, 2006). Research and development bases in different continents were continually established to adapt platforms from Japanese centers to local customer tastes (Fuchs, 2007).

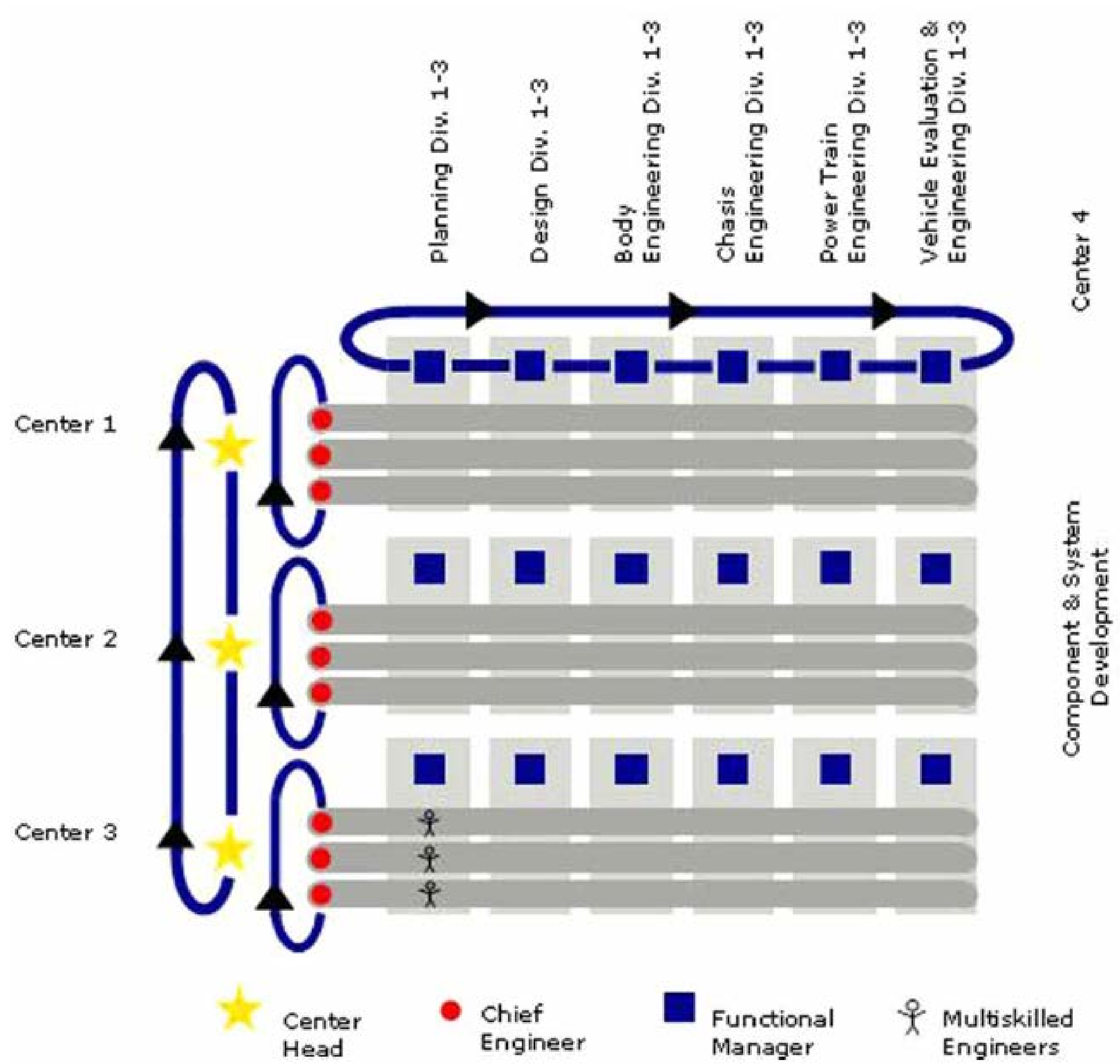


Figure 6. New Product Development Organization After Restructuring. Source: (Fuchs, 2007)

The restructuring results were excellent. Within four years, the cost for each development project was reduced by 30% in average, a decrease of prototypes by an average of 40% and the average lead time was shortened to about 18 months. All these above improvements made Toyota back into the lead in worldwide. Sharing component and platform, intensive coordination between functions and departments, and internal communication and interaction among centers are the primary sources for improvement (Fuchs, 2007).

A series of detailed studies have researched various aspects of Toyota Product Development System (TPDS). However, these studies are isolated. To understand what made Toyota's product development so successful, Morgan conducted an in-depth survey of TPDS through more than 1,000 hours of interviews held with Toyota and supplier representatives at different sites in the U.S. and Japan. Then Morgan published his findings together with Liker in the book named *The Toyota Product Development System*, in which the authors described TPDS as an integrated system of people, process, and tools and technology consist of 13 Lean Product Development principles (Morgan & Liker, 2006).

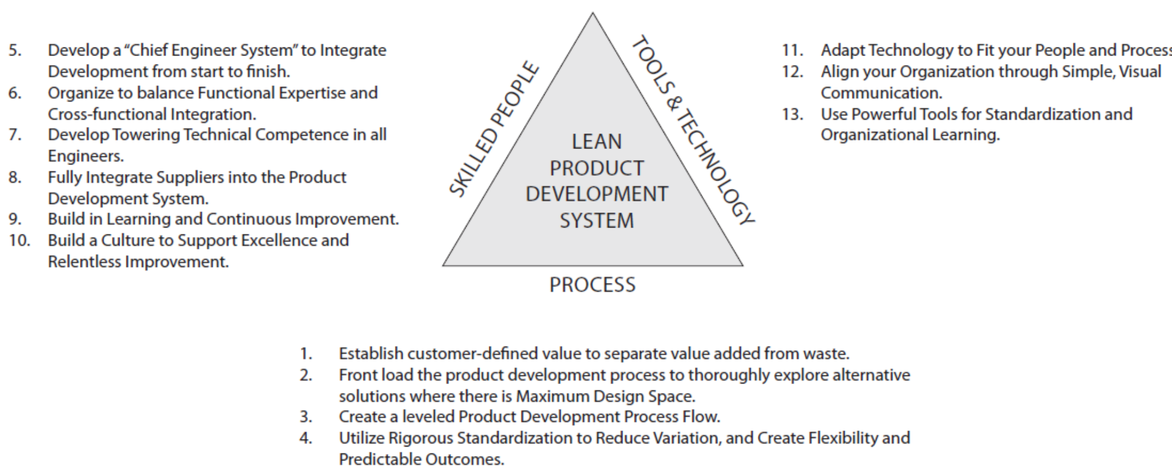


Figure 7. The Thirteen Principles of the Toyota Product Development System. Source: (Liker & Morgan, 2011)

Morgan and Liker (2006) also explained how Toyota can develop a new car in 15 months while their competitor needs at least 24 months in the book. They call it Lean Product Development System (LPDS), but it is different from the American lean and it is really Toyota's. The efficiency it achieves in the process is approximately four times that of the typical North American auto company.

The thirteen principles of the Toyota product development system are listed and illustrated below (Panview.nl, 2016):

The first category of principles is about PROCESS, which means bringing the product from concept to production. It includes the first four principles.

Principle 1: Establish customer-defined value to separate value added from waste. The primary objective of lean is to remove waste and maximize value to reduce cost and meet or exceed customer requirements. The dominant type of waste in product development is engineering waste (e.g. sophisticated design, access to knowledge or information not easily).

Principle 2: Front load the product development process to thoroughly explore alternative solutions where there is Maximum Design Space. Collaboration between different functions early in the design process and make sure rework is prevented. Set-based concurrent engineering is the core of the TPDS. Reasoning, developing, and communicating about sets of solutions in parallel and relatively independently.

Principle 3: Create a leveled product development process flow. Continuously improve the flow of the process by eliminating waste and synchronizing cross-functional activities. Value Stream Mapping (VSP) in product development is a useful tool to help find waste. In a VSP, the timeline with milestones are written on the top of the page, and important decisions and meetings are listed as process steps. Feedback loops should be visualized in the VSM as well.

Principle 4: Utilize rigorous standardization to reduce variation and create flexibility and predictable outcomes. Create a higher-level system flexibility by standardizing lower-level tasks including design standardization (e.g. common architecture, modularity, and reusable or shared components), process standardization (e.g. standardize tasks and work instructions, from design till manufacturing processes) and engineering skill set standardization (e.g. the right staffing and program planning guarantee flexible and skilled engineers). Adoption of rules and methodologies is also necessary.

When the processes are defined and improved, the second category of principles has to do with PEOPLE.

Principle 5: Develop a "Chief Engineer System" to integrate development from start to finish. The chief engineer is responsible for and can tell you the exact status of any given project. It is a vital role for each product development program. The chief engineer is not just a project manager but a leader and technical systems integrators.

Principle 6: Organize to balance functional expertise and cross-functional integration. Integrated traditional silos through the chief engineer. At Toyota, the chief engineer is responsible for the delivery of the product and the voice of the customer, while the functional manager is responsible for the development of his team members. Obeya (big room) is used to enhance cross-functional integration.

Principle 7: Develop towering technical competence in all engineers. To achieve technical excellence through the rigorous hiring process and establishing a career path for technical skills. Toyota prefers specialists over generalists.

Principle 8: Fully integrate suppliers into the product development system. Involve suppliers from the earliest stages in concept development of a product. Suppliers are valued for their technical expertise in addition to their parts-making capability. Companies should manger their suppliers the same way as they manage their own production. Tiered strategy for managing suppliers from those considered true partners to those who just supply off-the-shelf bolts.

Principle 9: Build in learning and continuous improvement. Reflection of the project on personal, team and project level. Toyota plans three 2-hour sessions of reflection after each project. This critical part of the process is often neglected, even though the ability to learn faster than competitors could be the only sustainable competitive advantage.

Principle 10: Build a culture to support excellence and relentless improvement. A culture is defined by the current generation of leaders and defines which leaders will emerge next. Leaders should, therefore, set the example of learning and always ask about the improvements.

How to use TOOLS AND TECHNOLOGY to help the people in the organization add more value to the customer is explained in the last three principles.

Principle 11: Adapt technology to fit your people and process. Traditional firms may alter their processes to suit a particular toll, but it is not correct. A tool or technology should be adapted to serve your people and process instead of replacing them.

Principle 12: Align your organization with simple, visual communication. Use lean tools to support communication between team members and between teams. Promote visual communication through training courses, workshops, and seminars. E-learning platform, handbook, website, and publications are also helpful. Finally, A3 sheets can be used for problem-solving on an individual level.

Principle 13: Use powerful tools for standardization and organizational learning. One could use decision matrixes and benchmark reports to visualize why a particular decision was made, which makes it easier to make a similar decision in the future.

The Toyota Product Development principles proposed by Morgan and Liker can also be concluded in three main categories (Rebentisch, 2007):

Category 1: Develop flow in core product development processes.

Defining customer value is the priority, then follow the most direct path to it in the design process by

- Reducing potential conflicts through trade space exploration and planning exercises
- Minimizing variance by reusing designs, using well-established routines, avoiding immature technologies
- Identifying and avoiding disputes through activist program leadership and boundary-spanning organizational structures and roles
- Relying on capacity buffers to minimize disruption when activities diverge from plans
- Continuous improvement and learning exercises update processes, tools, and behavioral routines

Category 2: Develop enterprise product development capacity.

Develop enterprise product development capacity (e.g. engineers and suppliers) through

- Closely supervised learning-by-doing and continuous improvement along well-defined advancement paths
- Experienced people filling key roles to ensure smooth and productive interactions across functions and boundaries
- Using informal organization structure with entrepreneurial roles to avoid formal organizational bureaucracy from stifling innovation around satisfying customer value
- A strong culture of well-defined standard work, performance transparency, and continuous improvement motivating failure identification and elimination

Category 3: Support a learning enterprise.

Structure work to allow coordination and diffusion of learning through the most straightforward communication modes possible by

- Adopting technology when necessary and automating or speeding up well-understood processes
- Partitioning work into independent tasks and defining simple, direct, targeted communication processes to clearly define the minimum actions required for coordination and alignment

- Leveraging standard work definitions (both process and product) to capture and diffuse experience and learning through checklists and other work summaries/guidelines

Ward summarized five vital elements of Toyota's Lean Product Development System that differentiates Toyota from its competitors (Ward & Sobek II, 2014):

1. **Value focus:** Focus on knowledge creation for profitable operational value streams.
2. **Entrepreneurial system designer (ESD):** Chief engineer who represents for the customer is responsible for all aspects of success for the product (profitability included). ESD cuts across boundaries but must be supported by strong functional departments.
3. **Teams of responsible experts:** Create a personnel system that rewards people for creating and teaching useful knowledge (knowledge that can be turned into profitable products).
4. **Set-based Concurrent engineering (SBCE):** Aggressively explore trade space up front and eliminate weak options quickly. Use tradeoff curves (updated continuously) to capture knowledge about crucial design decisions.
5. **Cadence, pull, and flow:** Release projects into the organization on a regular cadence, use integrating milestones to reduce the batch size of information transfers and establish pull (also as coordination mechanism across multiple groups).

The product development process consists of 13 principles inside Toyota that led to such innovative products as the Prius and the Lexus and positioned Toyota to surpass

GM and Ford to become the top worldwide automaker in 2007 (Radeka, 2007). Toyota's cars cost reduced by at least US$1,000 to make and their product development lifecycles take less than half in comparison with their competitors, with much less development cost. Their reaction to market change also had excellent performance. Hybrid technology and smaller cars were adopted to respond rapidly to rising gas prices, whereas their U.S. competitors struggled to react after making heavy investments in large sports utility vehicle development (Radeka, 2007).

The framework founded by Morgan and Liker is very comprehensive; however, the 13 principles of TPDS are broad and sometimes not mutually exclusive (Hoppmann, Rebentisch, Dombrowski, & Zahn, 2011). For example, "Principle 4: Utilize rigorous standardization to reduce variation and create flexibility and predictable outcomes" shows considerable overlap with "Principle 13: Use powerful tools for standardization and organizational learning". To give a single, clearly structured theory framework, Hoppmann et al. reviewed the literature published in this field and proposed a coherent and robust framework for Lean Product Development. In what follows, the 11 Lean Product Development components are described (Hoppmann, Rebentisch, Dombrowski, & Zahn, 2011).

Component 1: Strong project manager. At Toyota, the Chief Engineer conducts extensive research and analyzes competitor products to understand what the customer values at the beginning of a project. The role of the Chief Engineer includes not only the definition of project milestones and the negotiation of deadlines with development engineers but also the derivation of clear cost and performance targets for particular components.

Component 2: Specialist career path. It usually takes 10 to 12 years for promotion to a first-level management position for a Toyota engineer. The engineers hired after rigorous hiring process go through a period of intensive on-the-job training in order to cultivate technical expertise and a standardized skill. They should have a high level of demonstrated skills before slowly climbing up the career ladder. This kind of specialist career path help engineers build the required knowledge base for the system-level problem-solving and continuous improvement activities.

Component 3: Workload leveling. Leveling the workload of engineers through measures of resource planning and control. By combining flexible staffing and the use of external satellite companies to which work can be outsourced, Toyota compensates excess resource demands.

Component 4: Responsibility-based planning and control. Breaking higher-level goals down into meaningful lower-level objectives and aligning them across different stakeholders through extensive negotiations. The engineer is free to do his work as long as he can achieve a milestone on time no matter when to start and which approach to use. Frequent project reviews are conducted using andon boards and visual management. Each project member can check his own performance to determine if some adjustments are needed to meet the deadlines of each milestone.

Component 5: Cross-project knowledge transfer. The knowledge of previous products should be appropriately captured and used. Toyota has built a part-specific checklist containing the lessons learned over the years for every significant part of a vehicle. The checklists list the steps not to be missed during the design process and provide highly detailed visual information. It is a guideline for engineers when making decisions and facilitates the design review activities. The checklists are updated continuously, and their experience is abstracted using trade-off curves that graphically describe the governing influence factors determining performance and failure modes of a part.

Component 6: Simultaneous engineering. Module development teams (MDT) and the Obeya (big room) are used in Toyota to foster simultaneous engineering. MDTs are cross-functional teams whose task is to achieve the performance requirements given by the Chief Engineer and resolve critical challenges early in the process. Each of the MDTs is assigned one or more designated simultaneous engineers (SE) who serve as program-dedicated representatives from manufacturing. The Obeya serves as venues for regular meetings between the chief engineer and the leaders of the functional groups. The status of the project is posted on the wall of Obeya to enhance cross-functional collaboration between functional engineers.

Component 7: Supplier integration. Toyota incorporates key suppliers (typically two or three per part) during the concept stage of product development by pre-sourcing arrangements. The key suppliers are actively participating in the design process to improve the product and help solve design issues. However, the critical knowledge is handled by Toyota. The strategic importance of parts is carefully evaluated before its development is transferred to suppliers. Development and production of essential elements are kept within the company and not outsourced so as to maintain control.

Component 8: Product variety management. It means to make use of commodities, reuse parts, and define modular components and product platforms. Using cataloged parts from suppliers and reusing product parts among different modules, products, and product families as well as subsequent versions of the same product. Besides, Toyota tries to divide the products into distinct modules and subassemblies with a standard interface, and furthermore make use of product platforms to use modules across several product lines and maximize the reuse of parts.

Component 9: Rapid prototyping, simulation, and testing. The first prototypes are assembled very carefully to check the interfaces of subassemblies in Toyota. Then all subsequent prototypes are produced and assembled using Lean Manufacturing techniques. The Lean Manufacturing techniques help the Toyota supplier Delphi in one instance cut times for simulation and tests from weeks and months to 24 hours each. In recent years, computer-aided modeling, simulation, digital assembly, and 3D prototype printers facilitate the identification of problems and reduce the development time.

Component 10: Process standardization. To identify these reoccurring tasks across different projects and standardize them to increase product development performance. From a macro perspective, predefine a sequence of project milestones is a standard way of regulating processes. It helps engineers develop a certain routine and gain a deeper understanding of their role in the overall value stream. Also, it facilitates the planning and alignment of shared resources for multiple projects management. At Toyota, for example, engineers use “five whys” to analyze the root cause of a particular problem, and special decision matrices to support problem-solving. Additionally, A3-reports are used for documentation and communication of information.

Component 11: Set-based engineering. A large number of possible solutions are proposed at the front-end of the product development process for each product module. Engineers design, test, and analyze multiple solutions for every subsystem in parallel.

Only when a solution has been proven to be inferior to other designs, this design is removed from the solution space. The set of alternatives is gradually narrowed down and finally converges to a single solution. Once this single solution has been decided, it remains unchanged until starting of production unless altering the solution is absolutely necessary.

The philosophy of lean product development is to surface problems, solve them one by one, and then learn so the same problems are not repeated. This is the backbone of what made Toyota so successful (Liker & Morgan, 2011).

Ford Motor Company learned the principles from Toyota and created a Ford system of development combining their actual environment and organizational and national culture. In addition to Toyota, Ford used Mazda as a benchmark and learned the insights and methods from it. The Global Product Development System created by Ford allowed Ford to leverage their strengths as a multi-national and move to a global product development process since 2004. Ford transformed their automotive body development to lean product development, including all the stamped and welded steel structures of the underbody, upper body, and closures. The reason why they focused on the body and stamping development is that it is critical to new vehicle development and historically a major bottleneck to launching new models on time, at targeted cost, with high quality (Liker & Morgan, 2011). The results achieved by Ford is remarkable. From 2004 to 2009, Ford has surpassed benchmarked levels of performance for quality, lead time, and cost. For example, they reduced average overall lead time by 40% and internal tool investment costs by an average of 45% (Liker & Morgan, 2011).

Chapter 4 – World Class Engineering (WCE) Approach

4.1 World Class Engineering (WCE) Introduction

The World Class Engineering (WCE) program has been made by Prof. Hajime Yamashina at the Fiat Group Automobiles (FGA) from 2013. Before introducing the WCE approach, an automotive value chain analysis has been made to illustrate the aim of WCE.

Figure 8. Automotive Value Chain

The typical automotive value chain is shown in Figure 8. The automotive value chain consists of primary and secondary activities. The primary activities are involved in the current vehicle production while the secondary activities are involved in New Product Development (NPD) and support existing production. Improving margin generated by value chain means improving customer willing to pay (price) by hitting the market with exceptional products (quality perceived, conformity, lead time) and reducing the cost of the entire value chain.

Fiat Chrysler Automobiles (FCA) has implemented World Class Manufacturing (WCM) approach to improve primary activities, which is defined as a structured and integrated production system that encompasses all the processes of the plant, the security environment, from maintenance to logistics and quality (De Felice, Petrillo, & Monfreda, 2013). WCM is a continuous improvement program focus on Manufacturing activity with the aim to increase conformity delivered by transformation activities (effectiveness) and cost reduction of manufacturing activities itself (efficiency). Although primary activities could be improved through specific programs (e.g. Manufacturing WCM), the cost structure and performance of these largely depends on what was decided in the development phase of a new product and/or manufacturing plant (subtasks). The development of a new product has a significant impact on the total cost of the product itself, as shown in Figure 9. For this reason, it is necessary to involve the design function (Product Development, Manufacturing Engineering) in the continuous improvement program. The aim of WCE is to improve the value chain through the coordination and integration of design activities.

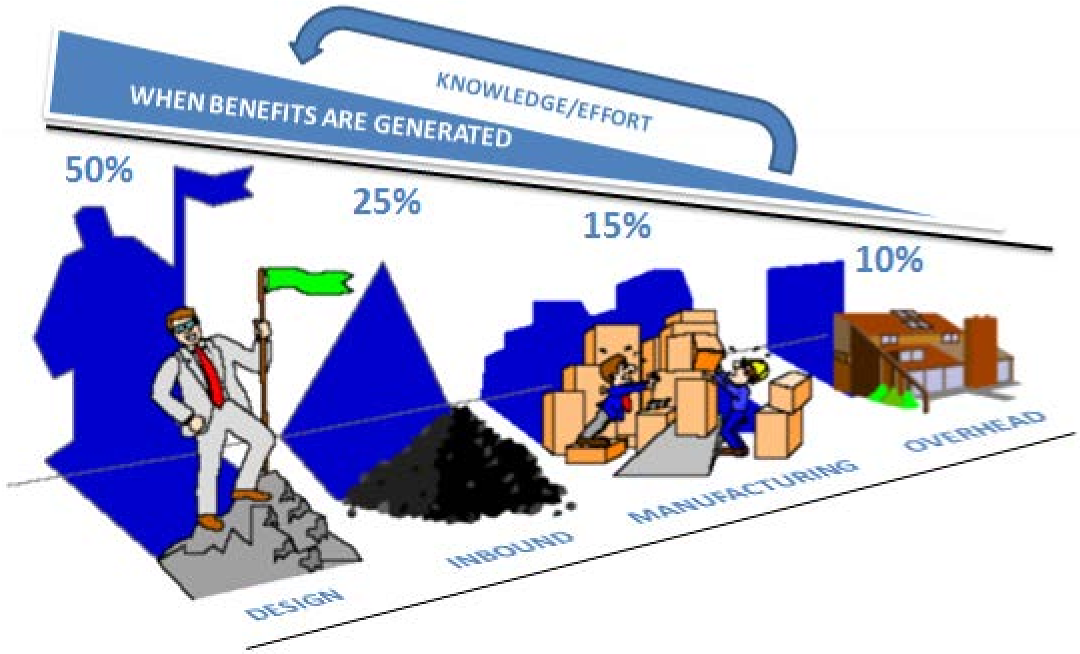


Figure 9. Typical Impact of Activities on Product Cost

The framework of WCE consists of 10 technical pillars and 10 managerial pillars. Each technical pillar is developed in 7 steps. The approach of WCE starts from a "**model area**" and then extend to the entire company. WCE is based on a system of audits that give a score that allows getting to the highest level. The highest level is represented by "*The World Class Level*". If we compare the WCE approach to a temple, the ten technical pillars will be the columns, and the ten managerial pillars will be the foundation. The list of 10 technical pillars and 10 managerial pillars are shown in Figure 10 and Figure 11.

Figure 10. List of WCE Ten Technical Pillars

Figure 11. List of WCE Ten Managerial Pillars

Here below in Table 1 illustrates the scope and purpose of each technical pillar.

Technical Pillar	Scope	Purpose
Market Research (MR)	Show what happens in the market	Understanding the needs, wants, desires by each segment before developing products within a 10-year vision. Discovering unmet needs by performing proper business analysis; benchmarking with competitors' products. Measuring the profitability of products, territories, customer groups, segments, and order sizes. Making a move to the future to drive R&D and Product Planning and satisfy specific needs.
Research & Development (R&D)	Development themes on customer request and competitors	Developing unique technologies and attractive products to satisfy the market, with: • A technological positioning of 10 years; • An industrialization plan of 5 years; • Exceeding customer requests; • Anticipating competitors; • Concurrent Innovation with Manufacturing and Quality.
Product Planning (PP)	Product Plan deploying product strategy, with target costing and profit analysis and risk management	Providing a Road Map for delivering new attractive products with a 10-year vision, to satisfy customer needs and wants. Indicating the key priorities for development and enhancement and linking the insertion of technologies into products. Reduce the payback time of new products concerning the initiative. Establish a company-wide system to take countermeasures against risks before SOP. Improve the cash flow of the company.

Technical Pillar	Scope	Purpose
Design (DS)	Develop functions focused on target cost and performance	Fully design each system/subsystem/component in coherence with the assigned targets and managing all the required trade-offs between the different performances, the quality, and the costs. Achieving World Class efficiency, regarding total design effort, project lead time and product Delivery time (D).
Early Product Management (EPM) Cost Deployment (EPM CD)	Budget and contingency setting and tracking of project cost and scheduling	Establishing a cost reduction program, scientifically and systematically, with the cooperation between Finance and Product Development department, in order to generate savings. Improve efficiency, people growth and involvement, productivity, quality, customer service, and market share.
Support Technology (ST)	IT tools support benchmarking activities ad hoc Product reliability test	Supporting Design to reach Q, C, D targets, by: • IT Tools support (CAD/CAM/CAE, simulation, etc.); • Benchmarking activities and Reverse Engineering; • Prototyping and evaluation; • Reliability testing; • Production Engineering.
Process Management of Product Development with Concurrent Engineering (CE) (PM CE)	Respect milestones	Involve all the concerned divisions to participate from the early stage of product development with Concurrent Engineering. Reducing tuning modification loops, eliminating modifications after design freezing and scraps after SOP (Q); shortening the effort time and reducing development costs (C); shortening product development lead time (D). Defining the methodology to improve product lead time and reduce cost: Analyzing the curve of changes, reducing them, and making Front Loading; Analyzing the planning to eliminate bottlenecks, waste and losses;

Technical Pillar	Scope	Purpose
Knowledge Management (KM)	Organize internal explicit and tacit knowledge	To reduce effort time and increase designers' productivity, making all necessary design knowledge available: • At the right time; • In the right place; • With zero effort in searching, opening, finding information inside the documents and in understanding the document contents.
People Development (PD)	Develop and acquisition of skills asked by departments	To develop accountable and competent Leaders and Engineers.
Office Environment for Creative Work (OE)	Office maintenance	The creation of a productive and creative environment to: • Increase people satisfaction; • Improve productivity; • Increase outstanding patents.

Table 1. 10 Technical Pillars Description

The first three pillars, which are Market Research, Research & Development, and Product Planning, are mapping the product plan phase. The understanding of customer and market and technology trend is of vital importance in proposing a robust product plan. Once the product plan has defined, the subsequent product development phase could start. The product development phase involves Design, EPM Cost Deployment, Support Technology, and Process Management of Product Development with Concurrent Engineering pillars. This phase aims to achieve the quality, cost and delivery time target defined in the product plan. As for the last three pillars, which can be grouped as the capabilities of the organization, plays a crucial role to support and facilitate all the pillars. They aim to create a creative and motivating environment and increase the best know-how and competences level.

As regards the ten Managerial Pillars there are: 1) Management Commitment; 2) Clarity of Objectives; 3) Route Map to WCE; 4) Organization; 5) Commitment of Organization; 6) Competence of Organization; 7) Allocation of Qualified People to Model Projects; 8) Time and Budget; 9) Level of Detail; 10) Motivation of Staff. The focus and responsibilities of management are illustrated below in Figure 12.

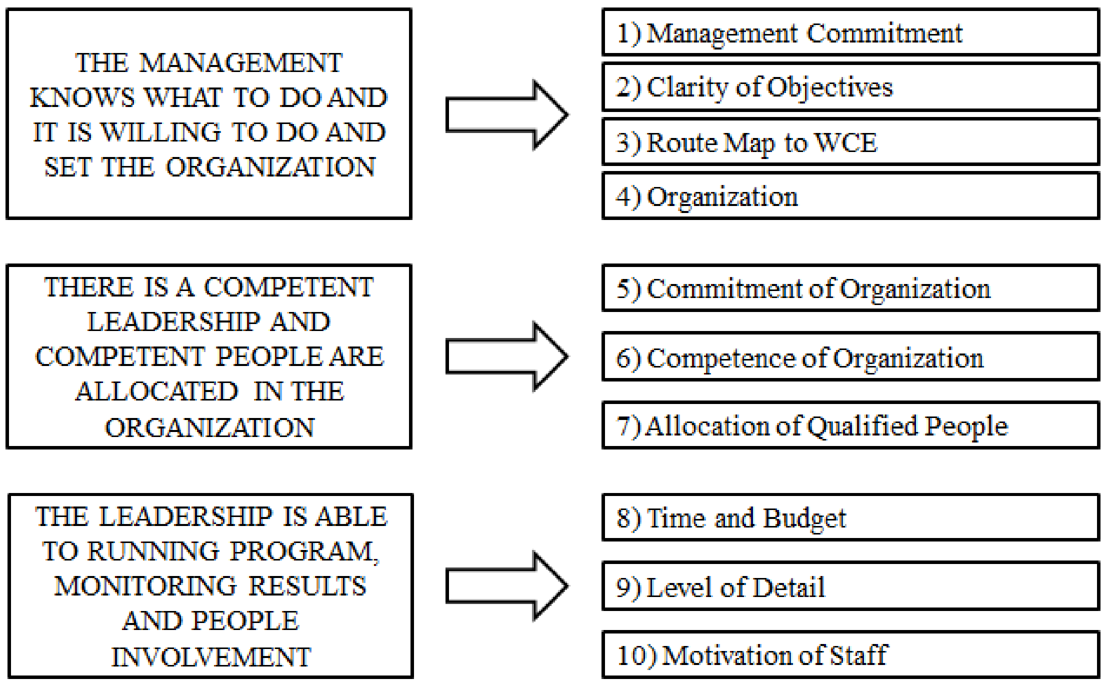


Figure 12. Managerial Pillars Responsibilities

Each managerial pillar has five key success factors and these factors are used to evaluate the achievement level of management. The key success factors of each managerial pillar are listed in Table 2.

Managerial Pillar	Key Success Factors
1) Management Commitment	1. Vision 2. Policy 3. Understanding 4. Alignment of the organization 5. Review
2) Clarity of Objectives	1. Objectives 2. Consistency 3. Measurement 4. Deployment 5. Evaluation
3) Route Map to WCE	1. Route map to WCE 2. Benchmarking 3. Education/Training 4. Communication 5. Unification
4) Organization	1. Responsibility 2. Flexibility 3. Flat, slim organization 4. Alliance 5. Suppliers
5) Commitment of Organization	1. Mindset 2. Overall view 3. Zero optimum concept 4. Involvement 5. Delegation
6) Competence of Organization	1. Methods/Tools 2. Planning ability 3. The capability of collecting information to resolve identified issues 4. Analytical capability 5. Continuous learning
7) Allocation of Qualified People to Model Projects	1. Allocation of highly qualified people to model projects 2. Leadership 3. Know-how transfer by education/training 4. Standardization 5. Documentation

Managerial Pillar	Key Success Factors
8) Time and Budget	1. Time 2. Response time/Lead time 3. The budget of product development cost 4. Budget of WCE 5. Follow up
9) Level of Detail	1. Understanding customers' needs and wants 2. Stratification 3. Root cause analysis 4. Visualization 5. Logic, methods/tools, rigor
10) Motivation of Staff	1. Small group activity 2. Behavior 3. Training session/presentation day 4. Absenteeism 5. Recognition & rewarding system

Table 2. Key Success Factors of Managerial Pillars

In WCE the focus is on continuous improvement. All the involved technical and managerial pillars are essential to the achievement of a better result. Efficient coordination and active cooperation is the key to success. In this thesis, the focus is on EPM Cost Deployment, a key pillar into the WCE program. The objectives and goals, and the seven steps approach of EPM Cost Deployment Pillar are introduced.

4.2 EPM Cost Deployment

Cost deployment can be divided into product cost deployment which is managed by Design Pillar and project development cost deployment which is led by EPM Cost Deployment Pillar. In this thesis, the focus is on the project development cost development. EPM Cost Deployment aims to improve the traditional approach, based on budget setting and target cost monitoring, introducing the understanding, identification, and analysis of Waste & Losses in the Product Development Process, reducing them to the zero target. The typical team structure is shown in Figure 13.

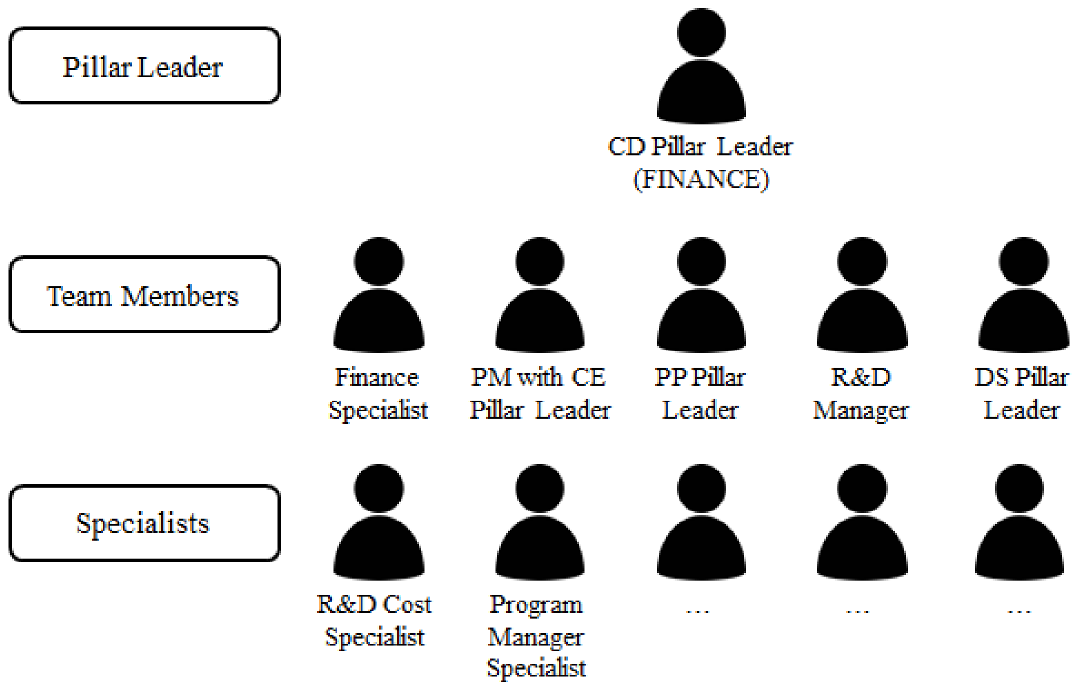


Figure 13. Typical Team Structure of EPM Cost Deployment Pillar

EPM Cost Deployment follows the same path of implementation of the other pillars through seven steps. A matrix is prepared as an output of (almost) each step. The general description of seven steps approach is illustrated as follows:

Step 1: Identify waste and losses in product development and establish a target for cost reduction.

Step 2: Detect where they take place (A Matrix).

Step 3: Separate and relate causal and resultant losses (B Matrix).

Step 4: Translate identified waste and losses into costs (C Matrix).

Step 5: Identify responsible functions and processes and choose right methods/tools to attack them (D Matrix).

Step 6: Estimate time, costs, resources for the product development and the amount of possible cost savings (E Matrix).

Step 7: Evaluate the achieved results and make a proper follow-up (F Matrix).

The detailed description is as follows:

Step 1 is to identify waste and losses in product development. First, the covered area should be defined. The covered area consists of total R&D cost perimeter and WCE extended cost perimeter. The total R&D cost is calculated starting from product development cost while the WCE extended cost is the costs that are not included in R&D cost but are strictly related to design change. Once the covered area is defined, the following activity is to stratify the covered area by departments and development phases. The total cost is separated into functions and processes. Second, a standard list is developed to identify waste and losses in product development. All the activities not contributing to the development of new innovative and attractive products are either waste (no contribution or overspending than needed) or losses (not effectively used). Typical waste in the design process are, for example, preparing new drawings, retrieving or searching for drawings or material, permitting designers to set their own schedules, questioning unclear requirements and specifications, attending too many meetings and conferences, reading and answering too many e-mails, designing new estimate drawings and reference drawings, altering designs to correct defects, etc. A standard list of waste and losses is given in Table 3. The tools used to daily collect R&D hours, costs and design change W&L are DEC, SAP, design changes register, equipment B/D register, and DEC EVO.

Categories	Major Losses	Descriptions
1. PEOPLE	1.1 Internal engineering activities on lost offer	a) Internal engineering hours on not acquired projects
	1.2 Rework engineering due to external resources mistakes	a) Rework engineering due to external Buy resources mistakes b) Rework engineering due to external Codesign resources mistakes
	1.3 Design change request by customer	a) Product performance change request
	1.4 Avoidable design change if we could have checked earlier	a) Weak determination of internal specification b) Weak determination of supplier specification c) Weak method or procedure d) Lack of checklist
	1.5 Engineering hours on design change	a) Inspection and control activity b) Reporting activity c) Adjustment activity d) Rework activity e) Testing activity f) Analysis activity
	1.6 Processing market claims hours	a) Receiving, managing, and fulfilling market claims activity
	1.7 Management loss	a) Unbalanced resources b) Unbalanced project planning c) Lack of internal communication d) Lack of communication with the supplier e) Lack of communication with the customer
	1.8 Stop or slow	a) Loss due to resources not present at work b) No skill resources
	1.9 Loss due to people training	a) Training hours
	1.10 Meeting & Travel loss	a) Meeting customers b) Meeting external consultant c) Meeting suppliers d) Travel loss for joint/team work
	1.11 Over design	a) Over engineering b) Over testing

Categories	Major Losses	Descriptions
1. PEOPLE	1.12 No value added activities	a) Motion/Transportation b) Redundant activities - over processing c) Redesign solutions or components d) Time to get access to the database and searching for documentation e) Time to understand new specification or customer documentation f) Waiting for software or hardware respond g) Other no value added activities
	1.13 Lack of information on customer requirements	a) Not all the departments can get access to the CCP
	1.14 Bad communication	a) Not effective communication between different regions
2. EQUIPMENT	2.1 Breakdown	a) Loss due to CAD station, CAE station, server, or test equipment down
	2.2 Tools performance	a) IT Tools and equipment performance loss
	2.3 Equipment missed or inadequate	a) Not available at all people involved in the project (especially PC)
	2.4 Set-up & Adjustment loss	a) Loss due to setup for CAD and CAE (Simulation) station, testing, measurement equipment
	2.5 Simulation/Evaluation time loss	a) Extra time to do simulation not planned b) Extra time to do evaluation not planned c) Extra time to do reliability test not planned
3. MATERIALS	3.1 Loss on prototype or samples	a) Loss due to samples or components
	3.2 Extra cost plant	a) Existing components obsolescence cost b) Existing finished products obsolescence cost c) Material scraps
	3.3 Over documentation	a) Over documentation

Categories	Major Losses	Descriptions
4. EXPENSES	4.1 Market claims	a) Warranty penalty b) Yard holds c) (0 km) Return penalty e) Customer line stop penalty
	4.2 Product extra cost	a) Delta cost component b) Delta cost finished product
	4.3 External consultant engineering activities	a) External consultant engineering expenses on not acquired projects b) External consultant engineering expenses on redesign activities
	4.4 ED&D Activities (Codesign)	a) Cost anomalies ED&D / Codesign b) Design technical competence not adequate c) The number of supplier resources not sufficient (to cover the specific project and the amount of work acquired) d) Claim management overlapping with new specifications management
5. PROCESSES	5.1 Product description changes	a) Development of components/functionalities but not become part of the car approval.
	5.2 Sourcing process	a) Need for partial redesigns due to the late involvement of suppliers
	5.3 Synchronization of Manufacturing-Engineering processes	a) Experience on the past projects not systematically occurs on all new projects
	5.4 Commercial launches synergies	a) Engineering changes for 2° motor launches
	5.5 Style rethinking after the project has been frozen	a) Introduction of changes, both in the planning and tooling phases
	5.6 Development of innovative components	a) Application on the vehicle of innovative solutions without adequate support of the experimental plan
	5.7 Management of multi-regional projects	a) Single BOM management for multi-regional projects, lack of multi-plant management on Codesign b) Lack of structured process to manage design change for multi-regional projects c) Insufficient input data causes loss
	5.8 Lack of training on new IT tools	a) Delays in managing offers/assignments to new suppliers

Table 3. Waste & Losses Standard List

A clear map of product development process is a prerequisite to developing an effective and detailed cost deployment. The level of detail should be the one necessary to identify waste and losses. When the map is available, every activity must be analyzed by identifying possible waste and losses. Waste and losses must be measurable (not root causes) and measured. For this reason, the level of detail must be the one that allows the measurement. The recommended tool to map the process is Product Development Value Stream Map (PDVSM). During this step, the target cost savings in product development should also be established.

The second step is to identify waste and losses in product development process qualitatively. The process has been mapped in Step 1 using the value stream map; it is worthy to create a matrix (A Matrix) reporting on rows all the waste and losses founded and on the columns all the product development phases and departments. Then, for each waste and losses set the relationship between the waste and losses and the departments involved in the product development phase. It is based on the past operating data (if available) and experience or the measurement of waste and losses qualitatively. Sharing opinions and identification of functions and processes responsible are needed.

Then in Step3, the causal and resultant losses should be separated. A new matrix (B Matrix) is established to show the relationship between causal and resultant losses. The causal waste and losses are reported on rows divided by department and phase while on columns the resultant waste and losses are also listed by department and phase. The connection of the causal loss with its resultant losses is marked with an “X” or a symbol. All the resultant losses should be attributed to their causal losses and identified the real sources of losses. It must be taken into consideration that the relationship between one causal and one or more resultant loss must be referred to a specific location (department and phase). Each resultant loss reported on the columns of the B Matrix must have minimum one “X”, meaning at least one relationship with a causal loss. If no connection exists, there is no causal loss responsible for this resultant loss and the loss should be considered causal or causal & resultant.

As for Step 4, the identified waste and losses are translated into costs (C Matrix). The causal waste and losses identified have to be converted into money and classified by the nature of cost. Correlating causal and resultant losses established in the B Matrix and the hourly cost rate provided by finance are the necessary inputs to translate identified waste and losses into costs. In the columns are reported all the causal losses recognized in B matrix concerning their location. In the rows are the items of the financial statement which must be consistent with the formulas and rates that chosen for the translation into costs.

Step 5 is the identification of responsible functions, processes, and methods/tools to reduce/eliminate identified waste and losses (D Matrix). A proper method and technical strategy required to eradicate the attacked loss are identified. The purpose is to list all projects identified through C Matrix stratification and to define a proper method and technical strategy to eliminate the attacked loss. This is why D Matrix is known as “Loss – Know How Matrix”. The D Matrix identifies the lead pillar responsible for the reduction of a Causal Loss.

Step 6 is to estimate time, costs, resources for product development and the number of possible costs savings (E Matrix). E matrix provides all the primary information about each project, for example, the amount of loss attacked and the savings forecast, the area where the project is occurring, the project leader and so on. It is worth to note that the countermeasures would be applied to following projects to generate saving or benefits.

The last step of the seven steps approach is to choose proper projects and establish product development schedule and its implementation. Data monitoring of the entire improvement projects is requested and then following up to the next run. The saving will be seen only at the end of the resultant phase. F Matrix must contain the same number of project and the same list of loss category and loss type. Then, G Matrix can be developed to provide links between the financial budget and the R&D projects. This matrix is used to ensure that there is a plan in place to achieve the R&D objective for the following year. The G matrix is the end of a cost deployment iteration and it is the link to a new budget creation.

Chapter 5 – Industrial Case Study

This work aims to present establishments of the basic model of World Class Engineering (WCE) Early Product Management (EPM) cost deployment for the product development process at FCA, which allows attacking waste and losses exist in the project and reduce them to the zero target. A case study methodology was used to collect detailed information on a specific vehicle development project, from concept definition phase to ramp up period. The result of this research was to understand and analysis of waste and losses in the product development process and avoid the appearance of the same waste and losses in the following projects in order to achieve the target of cost reduction. The purpose of this study is to examine the waste and losses in the previous product development process and transform them into lessons learned and to develop a standard that could be used as a reference in the future. We will focus our attention on the EPM Cost Deployment Pillar.

5.1 Company Background

Fiat Chrysler Automobiles (FCA) is an automotive-focused industrial group design, engineers, manufactures and sells vehicles and related parts and services, components and production systems worldwide through 159 manufacturing facilities, 87 R&D centers, and dealers and distributors in more than 140 countries (Group Overview, 2018). The brands under FCA include Abarth, Alfa Romeo, Chrysler, Dodge, Fiat, Fiat Professional, Jeep, Lancia, Ram, Maserati and Mopar, the parts and service brand. It also operates in the components and productions systems sector through Comau, Magneti

Marelli and Teksid (Group Overview, 2018). The net revenues in 2017 were € 111 billion, and about € 4.3 billion was invested in R&D.

For FCA, responsibility means promoting economic well-being and social development, researching and adopting innovative, efficient and environmentally-friendly technologies to provide increasingly ecological mobility, implementing ergonomic solutions in plants, pursuing excellence with suppliers, and behaving with integrity and transparency in the relationships with stakeholders.

5.2 Statement of the problem, methodology adopted and result

The objective of this work is to improve the efficiency of each development process and activity through reducing waste and losses by:

- Introducing quick-win activity on models under developing.
- Planning the new processes related to the future developments.
- Risk assessment on development cost deviation.

We analyzed a recent product development project in FCA in order to improve the process that ensures the reduction or elimination of waste and losses appeared during the product development process. Here below is a description of the methodology and steps.

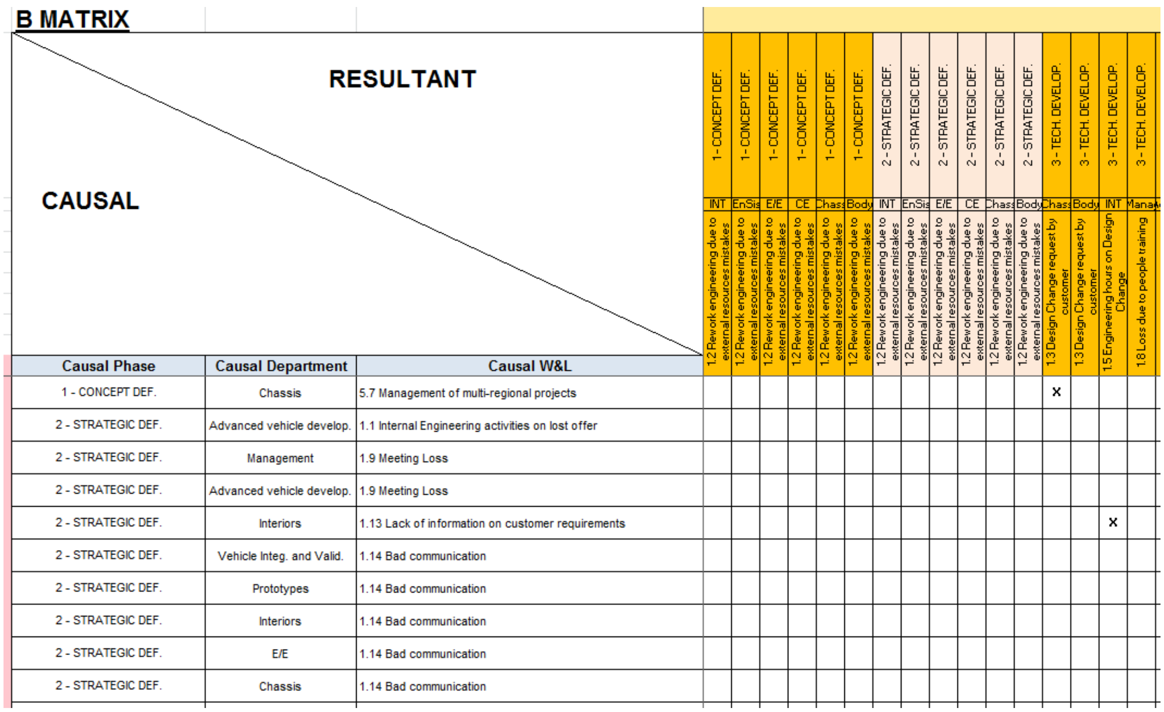
EPM Cost Deployment is a seven-step accounting technique for assigning actual costs to each waste and losses that happen during the product development process. The final target is to minimize or eliminate all the defined waste and losses. An additional advantage of EPM Cost Deployment is that all the departments are involved and assigned a saving potential according to the responsibility. This advantage motivates further improvements and is the best argument for convincing remaining skeptics. To do proper EPM Cost Deployment we team up persons as shown in Figure 13. Then we evaluated the total R&D expenditure of the vehicle and defined the covered area which is the starting point of Step 1. The perimeter expenditure analyzed including product development labor, electrical and electronical engineering, and builds. After that, we defined and identified waste and losses in the product development process according to the standard list which is given in Table 2. Moreover, in Step 2, A Matrix was built and part of the result is illustrated in Figure 14.

A MATRIX					PRODUCT DEVELOPMENT PHASES											
					1 - CONCEPT DEFINITION											
#	Categories	#	Major Losses	C/R	Management	Advance vehicle develop.	Design Systems	Vehicle Integ. and Valid.	U Connect Connectivity	Prototypes	Interiors	Engine System	E/E	Cost Engineering	Chassis	Body
A	People	1	1.1 Internal engineering activities on lost offer	C												
		2	1.2 Rework engineering due to external resources mistakes	R												
		3	1.3 Design Change request by customer	C/R												
		4	1.4 Avoidable Design Change if we could have checked earlier	C												
		5	1.5 Engineering hours on Design Change	R												
		6	1.6 Management loss	C/R												
		7	1.7 Stop or slow	R												
		8	1.8 Loss due to people training	R												

Figure 14. Part of A Matrix

The evaluation of the impact was classified into three levels. The green cells represent low impact, the yellow cells represent medium effects, and the red one means high impact. The evaluation in this step was a qualitative evaluation according to the experience.

The result of A Matrix was used as an input for Step 3. In Step 3, we separated the defined causal loss and resultant loss and built a relationship between them in a matrix which is named as B Matrix. For each resultant loss we could identify the root cause. A part of B matrix is shown in Figure 15.



B MATRIX

RESULTANT / CAUSAL

Causal Phase	Causal Department	Causal W&L	1 - CONCEPT DEF. INT 1.2 Rework engineering due to external resources mistakes	1 - CONCEPT DEF. EnSis 1.2 Rework engineering due to external resources mistakes	1 - CONCEPT DEF. E/E 1.2 Rework engineering due to external resources mistakes	1 - CONCEPT DEF. CE 1.2 Rework engineering due to external resources mistakes	1 - CONCEPT DEF. Chass 1.2 Rework engineering due to external resources mistakes	1 - CONCEPT DEF. Body 1.2 Rework engineering due to external resources mistakes	2 - STRATEGIC DEF. INT 1.2 Rework engineering due to external resources mistakes	2 - STRATEGIC DEF. EnSis 1.2 Rework engineering due to external resources mistakes	2 - STRATEGIC DEF. E/E 1.2 Rework engineering due to external resources mistakes	2 - STRATEGIC DEF. CE 1.2 Rework engineering due to external resources mistakes	2 - STRATEGIC DEF. Chass 1.2 Rework engineering due to external resources mistakes	2 - STRATEGIC DEF. Body 1.2 Rework engineering due to external resources mistakes	3 - TECH. DEVELOP. Chass 1.3 Design Change request by customer	3 - TECH. DEVELOP. Body 1.3 Design Change request by customer	3 - TECH. DEVELOP. INT 1.5 Engineering hours on Design Change	3 - TECH. DEVELOP. Manag 1.8 Loss due to people training
1 - CONCEPT DEF.	Chassis	5.7 Management of multi-regional projects													x			
2 - STRATEGIC DEF.	Advanced vehicle develop.	1.1 Internal Engineering activities on lost offer																
2 - STRATEGIC DEF.	Management	1.9 Meeting Loss																
2 - STRATEGIC DEF.	Advanced vehicle develop.	1.9 Meeting Loss																
2 - STRATEGIC DEF.	Interiors	1.13 Lack of information on customer requirements															x	
2 - STRATEGIC DEF.	Vehicle Integ. and Valid.	1.14 Bad communication																
2 - STRATEGIC DEF.	Prototypes	1.14 Bad communication																
2 - STRATEGIC DEF.	Interiors	1.14 Bad communication																
2 - STRATEGIC DEF.	E/E	1.14 Bad communication																
2 - STRATEGIC DEF.	Chassis	1.14 Bad communication																

Figure 15. Part of B Matrix

As for Step 4, we established C Matrix to translate identified waste and losses into costs. The cost was calculated according to internal R&D hours, co-design hours and material consumed. The total cost is the sum of all the value mentioned above. The cost of each causal loss was the sum of the cost itself and the cost of related resultant losses. Finance department provided all the value of the cost. Here below in Figure 16 shows a part of the C Matrix. It is worth to note that the data inside the C Matrix and afterward D, E, and F Matrix was modified for the commercial purpose to protect the interest of the company.

C Matrix

Loss Type		Loss	Phases	Cost Item	Cost Item 1	Cost Item 2	Cost Item 3	Total Cost
PROCESSES	1	5.7 Management of multi-regional projects	1 - CONCEPT DEF.	Chassis	€ 250.811		€ 35.213	€ 286.024
PEOPLE	2	1.1 Internal Engineering activities on lost offer	2 - STRATEGIC DEF.	Advanced vehicle develop.	€ 560.226			€ 560.226
PEOPLE	3	1.9 Meeting Loss	2 - STRATEGIC DEF.	Management	€ 82.345			€ 82.345
			2 - STRATEGIC DEF.	Advanced vehicle develop.	€ 158.302			€ 158.302
PEOPLE	4	1.13 Lack of information on customer requirements	2 - STRATEGIC DEF.	Interiors	€ 9.654	€ 134.696		€ 144.350
PEOPLE	5	1.14 Bad communication	2 - STRATEGIC DEF.	Vehicle Integ. and Valid.	€ 85.348			€ 85.348
			2 - STRATEGIC DEF.	Prototypes	€ 73.431			€ 73.431
			2 - STRATEGIC DEF.	Interiors	€ 112.798			€ 112.798
			2 - STRATEGIC DEF.	E/E	€ 362.848	€ 96.142	€ 93.462	€ 552.452
			2 - STRATEGIC DEF.	Chassis	€ 375.946		€ 49.056	€ 425.002
			2 - STRATEGIC DEF.	Body	€ 280.324		€ 64.351	€ 344.675
PROCESSES	6	5.6 Development of innovative components	2 - STRATEGIC DEF.	E/E	€ 129.835	€ 216.549		€ 346.384

Figure 16. Part of C Matrix

Then we identified the responsible apartments, phases, WCE pillars and methods/tools to reduce or eliminate identified waste and losses in D Matrix. We also evaluate the impact on KPI regarding quality, cost, delivery, and productivity. A part of the D Matrix is given in Figure 17.

In Step 6, we estimated time, costs, resources for product development and the number of possible costs savings in E Matrix. We defined the action plan, the potential savings coming from the action and the ongoing or future projects in development that can be affected by the action. All the projects which are countermeasures were listed and indicated with the necessary information. For example, the project responsible, the objective cost reduction, the forecast saving and the period of the project were given. Here below in Figure 18 shows a part of the E Matrix.

D MATRIX

Loss Category	Loss Type	Total Loss (€)	WCE Pillar						WCE Tools																										Impact on KPI			
			Market Research	Product Planning	Design	Support Technology	Process Management with	Knowlege Management	3 Types of CE Organization	7 Tools of Product Planning	CAD - DFM Integration	CAD Systems	CAE	Claims & Complaints	Design/Prototype and Evaluation	Design-In Concept with	DR System	FMEA	FTA	Market Claims/Complaint	PDCA	Preventive Claims Management	Product Development QA	Product Development	Purchasing Motives Analysis	QFD (The 7 Tools of MR)	Safety Factor and Robustness	Specifications of Parameters	Specifications of Tolerances	SWOT Analysis	Technological Trend Analysis	Technology S-Curve	TRIZ	VA/VE	Quality	Cost	Delivery	Productivity
PEOPLE	1.1 Internal Engineering activities on lost offer	560.226		P						X															X	X								X				
	1.9 Meeting Loss	240.647				X	P	X	X											X			X														
	1.13 Lack of information on customer requirements	144.350		X	P												X						X											X				
	1.14 Bad communication	1.593.706			X								X															X	X									
	1.3 Design Change request by customer	53.988	X	X	P									X			X				X		X											X					
	1.4 Avoidable Design Change if we could have checked earlier	32.240		X	X		P	X				X			X	X	X																						
	1.6 Management loss	126.983			P			X													X						X			X								
	1.6 Management loss	13.694					X													X										X								
	1.3 Design Change request by customer	43.088		X			X															X									X	X						
EQUIPMENT	2.5 Simulation/Evaluation time loss	13.845		X		X					X							X	X																			

Figure 17. Part of D Matrix

E MATRIX

N° WCE Project	Short Description of Project	Causal Phase	Causal Loss	Resultant Phase	Forecast Saving New Projects (€)	Saving Type				Project		PDCA			
						Hard Saving (€)	Virtual Saving (€)	Soft Saving (€)	Cost Avoidance (€)	Project Start Date	Project End Date	Plan	Do	Check	Act
1	Ensure an early management of common standard between different regions.	1 - CONCEPT DEF.	5.7 Management of multi-regional projects	3 - TECH. DEVELOP.	148.819			148.819		01/01/18	31/03/18	X	X	X	X
2	Evaluate the feasibility of the project as earlier as possible to minimize the internal engineering hours.	2 - STRATEGIC DEF.	1.1 Internal Engineering activities on lost offer	2 - STRATEGIC DEF.	160.090	160.090				01/01/18	31/03/18	X	X	X	X
3	Build a well-structured agendas for meetings considering resources allocation and eliminate unnecessary travel activities.	2 - STRATEGIC DEF.	1.9 Meeting Loss	2 - STRATEGIC DEF.	168.518	168.518				01/02/18	31/03/18	X	X	X	X
4	Make Customer Car Profile (CCP) available to all the departments.	2 - STRATEGIC DEF.	1.13 Lack of information on customer requirements	3 - TECH. DEVELOP. 4 - TOOLING DEVELOP.	99.480			99.480		01/01/18	31/01/18	X	X	X	X
5	Establish a communication network between different regions in order to certify the standards to be adopted.	2 - STRATEGIC DEF.	1.14 Bad communication	5 - PROCESS VERIFICATION + PRODUCTION READINESS 7 - POST J1 - Ramp-up	52.278			52.278		01/01/18	01/31/18	X	X	X	X
6	Define the standards to be adopted for prototypes in alignment with different regions.	2 - STRATEGIC DEF.	1.14 Bad communication	5 - PROCESS VERIFICATION + PRODUCTION READINESS 7 - POST J1 - Ramp-up	42.745			42.745		01/01/18	01/31/18	X	X	X	X
7	Communicate in advance for the standards of interiors in different rigions	2 - STRATEGIC DEF.	1.14 Bad communication	5 - PROCESS VERIFICATION + PRODUCTION READINESS	66.238			66.238		01/01/18	01/31/18	X	X	X	X
8	Establish a network to communicate effectively for the E/E standards in different regions.	2 - STRATEGIC DEF.	1.14 Bad communication	5 - PROCESS VERIFICATION + PRODUCTION READINESS 7 - POST J1 - Ramp-up	361.962			361.962		01/01/18	31/03/18	X	X	X	X

Figure 18. Part of E Matrix

There are four different saving types in E Matrix. The definition and description of each saving are illustrated in Table 4.

Saving Type	Definition	Description
Hard Saving	Saved money	Actual cost reduction achieved by improvement resulting in the reduction of people, material, energy, etc.
Virtual Saving	Not saved yet	Although improvement has been made, its saving is still latent since it has been made only partially and not to the extent that people or working hours can be reduced or more output/operator/hour has been achieved or less energy, less material was needed.
Soft Saving	Savings which will be achieved in the future	By working proactively from the design stage, able to minimize possible losses that may take place at later stages.
Cost Avoidance	The necessary expenditure to sustain the achieved savings	In order not to have a loss such as a breakdown, we need to have some AM and PM activities which cost money. To justify such expenses, we need to see the benefit by calculating possible losses in cash if we do not have such activities.

Table 4. Savings Definition and Description

We developed countermeasures to attack the losses identified in the analyzed project and then we would use these countermeasures for the ongoing or future projects. For example, we made an action plan to attack the losses detected in phase 5, the process verification and production readiness phase of Project M. The causal phase of this loss was phase 3, the technical development phase. Then we would apply these countermeasures in phase 3 of ongoing or future projects, which are Project X, Y, and Z. The saving would be generated in phase 5 of Project X, Y, and Z.

The last step was to choose proper projects and its implementation. The purpose is to provide economic data for the monitoring of the entire improvement of projects in F Matrix. The actual cost of WCE project would be compared with the budget every month. To connect the savings with the development of the product, we included both budget and actual savings for the current year and the next year. We would see the saving only at the end of the resultant phases, which means at the end of phase 5 in the last paragraph's example. A part of F Matrix is shown in Figure 19. Then the G Matrix which is used to provide links between the financial budget and the R&D projects would be developed to ensure the implementation of the plan for the following year. The G Matrix marks the end of a cost deployment iteration, and it is the link to create a new budget. The whole process is a continuous improvement activity which needs to be implemented in every new product development project.

F MATRIX

N° WCE Project	Short Description of Project	Saving Type: Hard Saving (€)	Saving Type: Virtual Saving (€)	Saving Type: Soft Saving (€)	Saving Type: Cost Avoidance (€)	BDG/ ACT	Total 2018 (€)	2018: 01/01/2018	01/02/2018	01/03/2018	01/04/2018	01/05/2018	01/06/2018	01/07/2018	01/08/2018	01/09/2018	01/10/2018	01/11/2018	01/12/2018	Total 2019 (€)	2019: 01/01/2019	01/02/2019
1	Ensure an early management of common standard between different regions.			148.819		BDG	88.851										45.160	43.691		59.968		59.968
						ACT	0													0		
2	Evaluate the feasibility of the project as earlier as possible to minimize the internal engineering hours.	160.090				BDG	160.090	26.451	25.910	24.619	27.910	28.164	27.036							0		
						ACT	160.090	26.451	25.910	24.619	27.910	28.164	27.036							0		
3	Bulid a well-structured agendas for meetings considering resources allocation and eliminate unnecessary travel activities.	168.518				BDG	168.518			30.000	40.000	36.000	62.518							0		
						ACT	168.518			30.000	40.000	36.000	62.518							0		
4	Make Customer Car Profile (CCP) available to all the departments.			99.480		BDG	99.480				28.600	26.300	30.000	14.580						0		
						ACT	99.480				28.600	26.300	30.000	14.580						0		
5	Establish a communication network between different regions in order to certify the standards to be adopted.			52.278		BDG	30.156										30.156			22.122	22.122	
						ACT	0													0		
6	Define the standards to be adopted for prototypes in alignment with different regions.			42.745		BDG	42.745					21.548	10.365	10.832						0		
						ACT	31.913					21.548	10.365							0		
7	Establish a network to communicate effectively for the E/E standards in different regions.			66.238		BDG	66.238					18.624	23.695	23.919						0		
						ACT	42.319					18.624	23.695							0		
8	Define the common standard for body development in different regions.			361.962		BDG	455.602			123.502	79.523	23.654	123.640	105.283						0		
						ACT	350.319			123.502	79.523	23.654	123.640							0		

Figure 19. Part of F Matrix

The cost deployment revolution chart is shown in Figure 20. The main results and savings can be summarized as follows:

- The identified losses occupy one-quarter of the defined WCE covered area.
- The proportion of forecast saving is 15.6%.

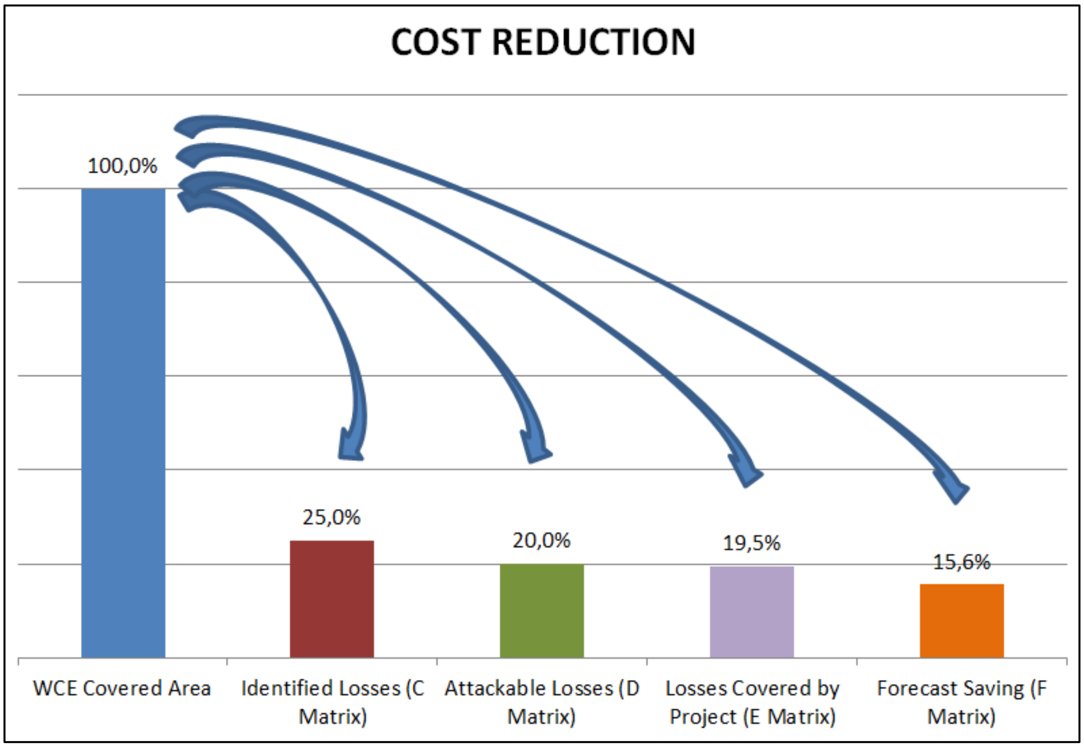


Figure 20. Cost Deployment Evolution Chart

Chapter 6 – Conclusion

As shown in the above thesis, the implementation of WCE EPM Cost Deployment methodology took place through the seven steps, and each step generated an output to fulfill the final target: identification of waste and losses during the product development process and establishment of WCE projects to attack identified waste and losses.

The EPM Cost Deployment revealed to be a useful methodology in the product development process. The main advantages of this method are:

- More effective and conscious control of the cost items related to the product development process, primarily to design change.
- All the departments and pillars involved in World Class Engineering program take parts in the process to improve their efficiency.
- All the identified waste and losses will be attacked.
- Continuous control over the improvement projects carried out in the product development process and a better calculation of the savings.

Apart from those cost benefits, EPM Cost Deployment can make all engineers more aware of the impact they have on the product development process. It helps them to understand how to avoid such waste and losses in the future project.

The methodology can be adopted by companies willing to improve their understanding of cost dynamics during the product development process and to identify waste and losses more clearly.

Product development excellence requires a long-term commitment both on an individual level and on an organizational level, and the journey never ends.

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