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The Way We Design: A design process and manual for industrial product development

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Abstract

The design work made by designing engineers need to be clearly defined and structured. The design process to follow should naturally lead to a systematic design work that reduce wasteful work, and reuses competence and knowledge from previous design work. The design process should lead to a design work that is made with as little lead-time and cost as possible, yet with a resulting part or product with the right quality. In a time when products become more complex regarding performance, tolerances, material, and with more technological and digital things built into the products, this design process becomes even more important. The Way We Design (TWWD) presented in this paper is one contribution to such a design process for the day-to-day design work. The work behind TWWD is based on both research and industrial practice. The process is built on 11 (A to K) number of checkpoints which gives details on the design work and is customised for the specific company.

Included in TWWD, as addition to the design work itself, are details regarding documentation and templates, standards, and directives. TWWD also include details of the design requirements from other departments within the company, such as sales, purchasing, assembly, manufacturing, painting and service. In this way, the designers can incorporate the requirements from their internal colleges and reduce much of the rework due to misinterpretations or design errors that are detected downstream in the manufacturing process or even at the customers. The TWWD process has been implemented at some companies as their manual for how to perform the design work. The results indicates that it is possible to reduce the design lead-time ranging from 5% to 20%, and with better precision in doing the right things and to reduce wasteful work. The design engineers at a medium and at a large company says that it is the resulting design quality that is the most beneficial from TWWD.

Keywords: Design work, design engineers, design process, lean product development

1 Introduction

To stay ahead of our competitors and to make sure that external customers and internal colleagues will get the most suitable parts and products, the actual design work shall be made as good as possible. Regardless if the design work is made in a large project; or if it is a small tolerance improvement, the designing engineers should know what to do and how. There are high expectations on the parts and products, not only by the end customer that is using products, or the competitors, but from many other areas as well. Some in-house expectations are typically coming from Marketing, Service, Assembly, Logistics, Manufacturing and Purchasing, Sales, Technical documentation, and Aftermarket. The design engineers have to make sure that all the thousands of parts will fit and comply with these expectations. Furthermore, a company have to be sure that they will be even better the next time they design something, regarding cost, quality, and lead-time. Finally, the company needs to assure that the design work follows and comply with standards, directives and legislation.

The background to the development of The Way We Design (TWWD), described in this paper and illustrated in figure 1, is that the design of parts and products need to follow a clear and defined design process in order to be successful. The success lies in doing the right things with as little effort as possible, and with no re-work. That is, to become more lean regarding the design work. This design process also needs to fit the day-to-day design work made by the designing engineers.

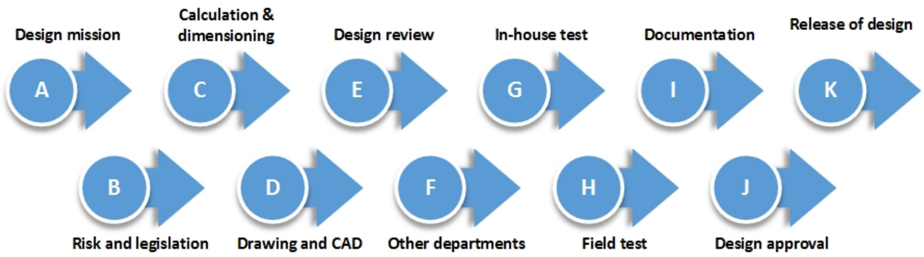

Figure 1: The Way We Design process.

TWWD is a design process and a design manual for industrial product development, made for the design engineers and their most frequent internal colleagues and collaborators. TWWD is the result from putting known and necessary design activities together in a stepwise description that forms a repeatable process for the day-to-day purpose; and act as a manual for how to design parts and products. The meaning with "industrial" product development is that the process includes all legal and standards requirements, as well as the documentation requirements that is required by companies by to follow. It also includes the possibility to detect not applicable design work, in order to reduce wasteful design work. Thereby the design process will naturally lead to a lean process for industrial design work. As with processes, it is an iterative work that may go back and forth. However, the start at A and end at K, figure 1, are the natural process during the design of parts and products. TWWD has been developed for more than 10 years, and is still being fine-tuned. Today, it has been implemented in some companies as the manual for how to design parts and products.

2 Product development processes

The research regarding product design processes itself has been going on at least since the early 1960s where the work by (Norden, 1960) is commonly cited. Even though (Nigel, 1993) mentions that the earliest work reported is from 1948. During the 1960s, the design process was poorly developed and was far behind the manufacturing process development. (Norden, 1960) says that the design work was a matter of art and craftsmanship, rather than science and system. The design work was at this time typically known for its creativity and uncertainty. The first Conference on Design Methods, was held in London in September 1962 (Nigel, 1993), which is known as the starting point of assembling researchers within the area.

Since the end of 1980s, product development processes and methods has been available to the industry. Some of the known and commonly cited literature that describes theories and processes in product design can be found in (Andreasen, 1992; Boothroyd & Dewhurst, 1989; Hubka & Eder, 1988; Pahl & Beitz, 1996; Pugh, 1991). These authors has made an important impact to the research community, and the education of engineers at universities worldwide. Furthermore, at 2000 (Ulrich & Eppinger, 2000) launched their book product design and development which since has been renewed each 4th year. The book summaries the work by other researchers and also contributes with the concept development process.

At the beginning of the 1990s, the modular design and product platform development emerged. However, companies has worked with modular product development since the 1930s. Scania, for example, initiated their modular development of truck components in 1939, (Olhager, 2000). IBM was a forerunner with their modular computer in 1964 when the System/360 was launched (Baldwin & Clark, 1997). The underlying ideas regarding standardization and modularity started already in 1914 in the automotive industry, (Fixson, 2007). One may even see Taylor's work in early 1900s as a predecessor to both development processes and modularisation (Taylor, 1911). His ideas on standardized and repetitive work have analogies with today's reasons why companies develop modular products, for example common unit- and carry over modules, see (Erixon, 1998). Also the work by (Radford, 1917) can be seen as one of the initiators of the modular thinking. Modularisation has been part of many companies way of designing products for the last 20 years. Many of them are described in (Erixon, 1998; Fixson, 2007; Kenger, 2006; Simpson, 2004).

During the last 2 decades, the Lean Product Development (LPD) methodologies has been developed. Based on the lean manufacturing methods, as described in e.g. (Baudin, 2002; Ohno, 1988; Womack & Jones, 2003; Womack, Jones, & Roos, 1990), the lean product development aims at identifying wasteful design work and doing things as stream-lined as possible. This has put a well-deserved focus on the design process. Some of the LPD work is based on, or inspired by, (Womack & Jones, 2003; Womack et al., 1990) and (Morgan & Liker, 2006). As with lean manufacturing, LPD should identify and remove wasteful processes or activities, and follow certain principles. For example, (Morgan & Liker, 2006) describes the lean way of Toyota which is built on 3 main areas; People, Process and Tools and Technology. Within these 3 areas, there are 13 principles to follow and apply in order to become leaner. Toyota is also the base for the book by (Kennedy, 2003) where the Knowledge Based Design are developed and described; which is another way of becoming a lean product development organisation.

Despite the research and available literature on product development processes, many companies have unstructured ways of designing parts and products. The authors own experiences is that this depends on an organic growth of company culture, just as described in (Morgan & Liker, 2006), this culture is difficult but essential to change. It is built-in into the day-to-day design work. New employees just follow old habits, instead of bringing new knowledge and ideas into the company. Still, most of the design engineers, design managers and management team are well educated and should know of better ways of designing things. At the same time, the methods and processes available in literature are on a high and abstract level, or they just cover a small piece of the complete design work, and are therefore not suitable for being implemented at the company. Also, available methods and processes assumes that a new product shall be designed. While much of the design work at companies are just small changes at parts, drawings, or at part number structures. For companies, the time and work to change their way of doing things seams too long and undefined. As a result, the company and designing engineers keep on doing things in the same (poor) way as before.

Research indicates that the design work have a huge influence on the internal manufacturing and assembly processes, as well as the final product cost. Work by (Barton, Love, & Taylor, 2001) concludes that there is little evidence of how much this influence actually is. However, the cost for the manufacturing and assembly process is partly a direct result by the design work. (Ulrich & Pearson, 1993) indicates that the design work determines 47% of the manufacturing cost, at least for a case at a coffee machine manufacturer. In this context, it is even more important that the design work is made according to a process that includes the demands from manufacturing and assembly, as well as other internal processes at the company.

Given the literature discussed in this section, it is justified to develop a design process that are detailed enough for design engineers to understand and adopt to, and which describes what and how they should do things. This design process shall guide the design engineers in their day-to-day work and include all essential parts as legalisation and standards, and be possible to monitor and manage during any design project. Documentation requirements shall also be part of a design process, so it is clear when and how to document the design work. The design process needs to be scalable and possible to adopt to different companies and products. TWWD described in the following sections is one such design process.

3 The structure of The Way We Design

TWWD is built on 1) a manual with checkpoints, 2) documents and templates, and 3) a checklist. Altogether, this will steer the design work to be efficient regarding cost, lead-time and quality. It will also support the design work to reduce wasteful work and to reuse competence and knowledge gained from previous design work. In this sense, one may see TWWD as a lean product development process as described in (Morgan & Liker, 2006) with regard to processes.

3.1 Checkpoints

The design process in TWWD consist of a design manual with checkpoints. The design manual includes and describes how these checkpoints shall be managed. The checkpoints ranging from checkpoint A (when the design work starts) to K (when the design work is completed), see figure 1.

Each checkpoint contains a question which needs to be considered by the design engineer, and answered with "**Yes**", "**No**", or "**Not applicable**" (**N/A**). To answer the question with **Yes** means that the checkpoint was necessary to complete and the work was performed with a positive result and at appropriate quality. To answer the question with **No** means that the checkpoint was necessary to complete, but the work was not performed at all, or did not comply with the intended quality. In this case, responsible person needs to approve the deviating work, or the checkpoint is reworked and completed. To answer the question with **N/A** means that the checkpoint is not necessary to complete and does not apply for the design work in regard.

Each of the checkpoints A to K contains a sets of sub-checkpoints, e.g. A1, A2, and A3. However, the day-to-day design work in the design of parts and products are unlikely to include all of the checkpoints in the process. A part of the design work are small design changes and updates. Therefore, the checkpoints are many times N/A and not necessary to complete.

The design engineers do however work according to TWWD without continuously reading the design manual. Nor do they move forward in a stepwise manner. As TWWD becomes implemented and familiar to the design engineers, the design work flow in a smooth and lead-time efficient way. Then TWWD acts as the red-line and the base for how the design engineers shall design parts and products.

3.2 Documents and templates

There are many reasons why documents and templates shall be a defined part of a design process. One reason is the legal demands on documentation that are described in directives such as the Directive of machinery (Union, 2006). Other reasons are the internal knowledge and competence that are documented in reports and guidelines. TWWD includes the most common documents and templates that are required in order to store, maintain and reuse knowledge gained during the design of parts and products. As a part of TWWD, a description of the documentation requirements are made at checkpoint I, as described in section 4.9.

3.3 TWWD checklist

At checkpoint A, the design work is started, and at checkpoint A2 a new TWWD checklist is established. The checklist is digital or in a paper format (depending on the way the company prefers) and follows the design work, checkpoint by checkpoint. When the design work is completed, and released at checkpoint K. The checklist is stored according to the documentation requirements. Normally at specific folder at the company´s common accessed files.

For a project manager, the checklist also acts as a project planner and status report. The project manager can manage the project by reviewing each design engineer´s progress in TWWD checklist.

3.4 A design with enough quality

The cost of poor quality (COPQ) brings cost of repair and a bad reputation among customer. The highest COPQ, regarding one single defect, is when that defect is detected after the product has been shipped to the customer. It may be difficult to estimate the actual COPQ for a customer detected defect (Roden & Dale, 2001), but there are lot of percentage described in literature. For example over 25% of sales (Juran & Godfrey, 1999), 20.2% of sales, a case in (Oakland, 1993), 20-40% of the total cost (Sandholm, 1997), and 20-30% of the total turnover (Sörqvist, 1998).

Due to the COPQ, the design work needs to be made in such a way that no design defects slips through into production or onto customers. However, to overwork the design of the part or product are not value adding for the customer or the company. The design of the part and product shall be good enough, see figure 2. Good enough means that the product fulfils all demands from legalizations, standards, directives, customers and the company’s own requirements. But not more, and not less. The answers to each checkpoints in TWWD (N/A, Yes and No), will support the design work to be good enough.

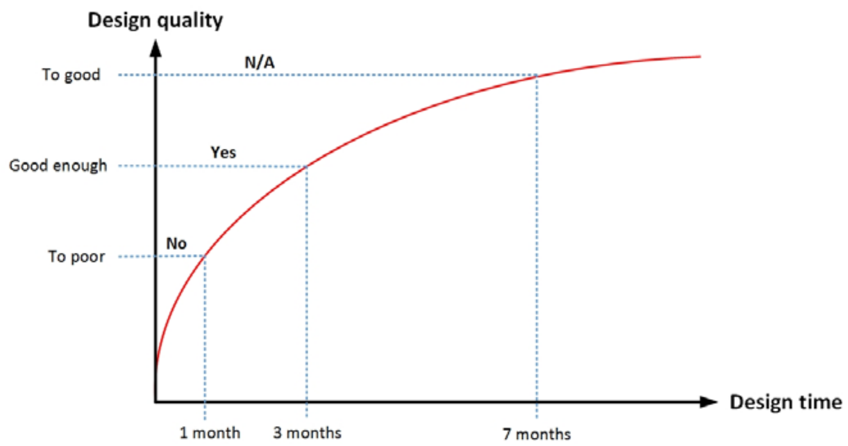

Figure 2: A good enough design and the answers (No, Yes, N/A) to the checkpoints in TWWD.

4 The checkpoints in TWWD

Here follows a short description of each checkpoint and its sub-checkpoints. Typically, the final TWWD checkpoint manual (once completed and implemented at a company) are approximately 100 pages. In the TWWD design manual, all checkpoints are explained at detailed level and adopted to the specific company. Due to the natural limitations in pages in this paper it is not possible to describe all checkpoints at a detailed level. But many of the checkpoints are known to researchers and industrial practitioners. The intention here is to describe the overall TWWD process and its coverage area.

4.1 Checkpoint A: Design mission

The purpose with checkpoint A, see figure 1, is to assure that the designer know what is expected from the forthcoming design work. The designer should also know why the work is needed. This knowledge will improve the result and the precision in doing the right things in the design work. The purpose is also to obtain necessary information in order to start the design work in the right direction. Important persons at this checkpoint are sales and project leaders that shall provide products specifications and key performance targets to the design work, and date for the release of the design (when the design work shall be completed).

The sub-checkpoints in A are the following. A1: The design specification, A2: A new TWWD checklist, A3: Understanding the design and functionality, A4: Preliminary design specifications, A5: Consideration of customer values, A6: Evaluation of alternative solutions, A7: Effects on other products, A8: Other issues to consider, A9: Product cost effects, A10: Part and product variants, and A11: Information to other personnel.

4.2 Checkpoint B: Risk and legislation

The purpose with checkpoint B is to minimize the failure risks in the design. The purpose is also to ensure that all legal aspects, environmental aspects, patent aspects and applicable standards have been followed. The sub-checkpoints in B are the following. B1: Comply with standards, directives and laws, B2: Forbidden materials and chemicals, B3: Design according to design guidelines, B4: Risk analysis, B5: Test routines and assembly instructions, and B6: Patents.

4.3 Checkpoint C: Calculation and dimensioning

The purpose of checkpoint C is to ensure that all necessary calculations have been performed in accordance to the dimensioning requirements for the part or product. When this checkpoint is completed, the product will fulfil the dimensioning requirements and will be safe to use during its life length. During the work with this checkpoint, the designer will gain good knowledge of the limitations and the influence of the chosen geometry, tolerances and material for the component.

The sub-checkpoints in C are the following. C1: Material selection, C2: Geometry and tolerances, C3: Dimensioning according to design guidelines, C4: Dimensioning according to specifications, C5: Structural calculations, and C6: Flow, pressure, and temperature calculations.

4.4 Checkpoint D: Drawings and CAD

The drawing is the defining document for all parts, assemblies and complete products. It is the most important and valuable document at many companies, and is the result of all the design work. However, the drawings and the CAD-models are sometimes poorly managed.

The purpose with checkpoint D is to ensure that all information necessary for manufacturing has been included to the drawings. Also that all legal and standard requirements such as marking is included on the drawings. The objective is to have a uniform way during the work with CAD-models and drawings in order to reach correct quality and short development lead-times. The sub-checkpoints in D are the following. D1: CAD parts, D2: CAD assemblies, D3: The parts function, D4: Drawing recommendations, and D5: Drawing review and approval.

4.5 Checkpoint E: Design review

The purpose with checkpoint E is to summarize and review the performed design work. The design review shall ensure that all requirements are fulfilled, and that all documentation (up to this checkpoint) is prepared and completed and ready for approval from other departments. The sub-checkpoints in E are the following. E1: General design review, E2: Prototype design review, and E3: Supplier design review.

4.6 Checkpoint F: Other departments

The purpose with checkpoint F is to ensure that the requirements from other departments (e.g. sales and assembly) at the company have been considered, fulfilled and approved. This means that the part or product should, whenever reasonably possible, be designed in such a way that it will fit the other department's way of doing things. Depending on which type of departments (or functions) there is at the company, checkpoint F will vary accordingly. Here are some of the most common departments described. It is each department that develops the checkpoints. In agreement with the design department, the final checkpoints is then set as a part of TWWD process.

4.6.1 F1: Compliance with Sales

Sales is the main contact with customers. Most of the design work for new products are initiated by the Sales department. In order to obtain orders from customers, and guarantee and quick supply of correct products, the checkpoints in F1 is important for the design department to comply with. F1 consists of the following sub-checkpoints. F1.1: Design in accordance with specifications, F1.2: Comply with the customer requirements, F1.3: Technical manuals completed at product delivery, F1.4: Product certified for relevant markets, and F1.5: Naming of parts.

4.6.2 F2: Compliance with Purchasing

Purchase department has a vital role in buying the best possible quality, to best possible price, and secure deliveries to the daily production; as well as the delivery of spare parts. The designers need to adopt to present suppliers of material and parts. It is the Purchasing department that identifies new suppliers and approve them before they can deliver parts to the company. Checkpoint F2 consists of the following sub-checkpoints. F2.1: Use existing design solutions, F2.2: Approved suppliers, F2.3: Supplier review, F2.4: Approved and verified solutions, F2.5: Standard parts from suppliers, F2.6: Internal standard parts, F2.7: Suppliers manufacturing process, F2.8: Design within cost targets, F2.9: Verified critical parameters, F2.10: Remarks on drawings required by law, F2.11: Article structures in the MRP system, F2.12: Design specification for purchase, and F2.13: 2D and 3D drawings.

4.6.3 F3: Compliance with Manufacturing

Manufacturing is the automated and manual manufacturing unit that manufactures parts that are not purchased externally. It is essential that Manufacturing gets the best possible prerequisites for their daily work. Therefore, whenever possible and justified, the design engineers need to adopt the design of parts to the manufacturing unit's prerequisites. F3 consists of the following sub-checkpoints. F3.1: Lifting points, F3.2: Design adopted to current fixtures, F3.3: Ergonomics in manufacturing machines, F3.4: Minimum fixture setup changes, F3.5: Existing machinery and tools, F3.6: Drawings, CAD-files, and specifications, F3.7: Drawings and dimensions for manufacturing, F3.8: Origin in CAD- and CAM-files, F3.9: Naming of parts, F3.10: Avoidance of universal drawings, and F3.11: Identical CAD-files and drawings.

4.6.4 F4: Compliance with Assembly

The assembly of the products plays an important role to deliver safe and qualitative products to customers. During assembly, part deviations are detected as well as poor performance during the tests. Assemblers need to have a safe work environment, in which the design of parts and products have an influence. Assembly lead-time are affecting the total cost for manufacturing and the delivery output from the factory. F4 consists of the following sub-checkpoints. F4.1: Use of existing design solutions, F4.2: Consideration of assembly issues, F4.3: Assembly space and access, F4.4: Use of assembly support, F4.5: Assembly ergonomics, F4.6: Reduction of chemicals in assembly, F4.7: Assembly specifications, F4.8: 3D-models for assembly support, and F4.9: Structures in the MRP system.

4.6.5 F5: Compliance with Painting

The painting of products has several important purposes. The paint protects surfaces and critical parts from oxidation and environmental impact. The protecting paint extends the life length and give the products a competitive performance. The paint and colours also marketing and positioning the company brand towards customers. Painting is a part of the total design-manufacturing-delivery lead-time. Hence, a simplified painting process will decrease the total lead-time to customers. The following sub-checkpoints are part of checkpoint F5. F5.1: Minimum radius measure, F5.2: Wedge shaped slots, F5.3: Access to small areas, F5.4: Countersink of screws and nuts, F5.5: Lifting and hanging of parts, and F5.6: Selection of materials.

4.6.6 F6: Compliance with service and aftermarket

Service and aftermarket are a major part of sales income and customer services. It is essential that the design of parts and products are made to fit the service and aftermarket demands. Foremost, it is important to identify spare parts, spare part kits, and their life length or replacement interval. But also that the parts are easy to replace in field or at any service station. Checkpoint F6 consists of the following sub-checkpoints. F6.1: Design solution and spare parts, F6.2: Use of existing design solutions, F6.3: Defined expected life length, F6.4: Design solutions verified trough tests, F6.5: Design according to service classifications, F6.6: Test specification for software, F6.7: Installation approval from suppliers, F6.8: Field- and internal issues, F6.9: New design solutions for field implementations, and F6.10: Installation drawings for field-kit.

4.7 Checkpoint G: In-house tests

The purpose with checkpoint G is to ensure that all required in-house tests have been performed, and that the products safely can be delivered to customers. Furthermore, the purpose is also to assure that required safety inspections are performed and documented. Checkpoint G consists of the following sub-checkpoints. G1: Safety inspection for in-house tests, G2: Performing assembly tests, G3: Performing bench tests, and G4: Performing functional tests.

4.8 Checkpoint H: Field tests

During the design stage of a new part or product, different kinds of field tests (external tests) may be required in order to assure a safe product that performs as intended. Field tests are made on prototypes, or on finished products before market release, or on already released products, in order to monitor and follow-up its performance. The main purpose with the field tests are to test the part or product´s performance at real conditions at customers. The objective with the field test is to ensure that only safe products with the right performance are delivered to customers. Checkpoint H consists of the following sub-checkpoints. H1: Plan and initiate field test, H2: Safety inspection for field test, and H3: Field test execution and approval.

4.9 Checkpoint I: Documentation

The purpose with checkpoint I is to ensure that all required documentation are completed, approved and filed according to company standards. The company standard way to document is described in their documentation requirements that is a part of TWWD. Checkpoint I consists of the following sub-checkpoints. I1: Operator manuals, I2: Service instructions, I3: Company documentation requirements, and I4: Company legal documents.

4.10 Checkpoint J: Design approval

The purpose with checkpoint J is to ensure that the design is approved and ready to be released to other internal departments, to suppliers, and to end customers. All information regarding safety and legislation are managed at this checkpoint. Including how the new part or product will be released (for example, if any parts or products shall be replaced). Checkpoint J consists of the following sub-checkpoints. J1: All checkpoints completed, J2: Safety inspection for market release of new product, J3: Declaration of conformity, J4: Design implementation priority (how the part or product will be released and its priority).

4.11 Checkpoint K. Release of design

The purpose with checkpoint K is to ensure that the design is released to the rest of the organisation in a correct way. This release information is also transferred onto suppliers if the part is made externally. At this checkpoint, all information of the parts and products are managed in order to secure that part numbers and product structures are correct. Checkpoint K consists of the following sub-checkpoints. K1: Parts information, K2: Release of a new part or product, K3: Release of a new purchased part, K4: Release of a new structure, K5: Release of a design change.

5 Measured and expected results

The time it takes to implement TWWD on a company depends e.g. on the complexity of the products with respect to parts and variants, how many departments and people involved, and how much is governed by standards and regulatory requirements. By comparison, TWWD has been implemented in a multinational company with 90 engineers distributed in 3 factories in different countries. From that time the company had develop their specific TWWD-process, it took approximately 6 months to breakeven in lead-time, see figure 3. A medium sized company with 4 designing engineers have had TWWD implemented. This company will have a much shorter time (3-4 months) to reach gain in lead-time and quality.

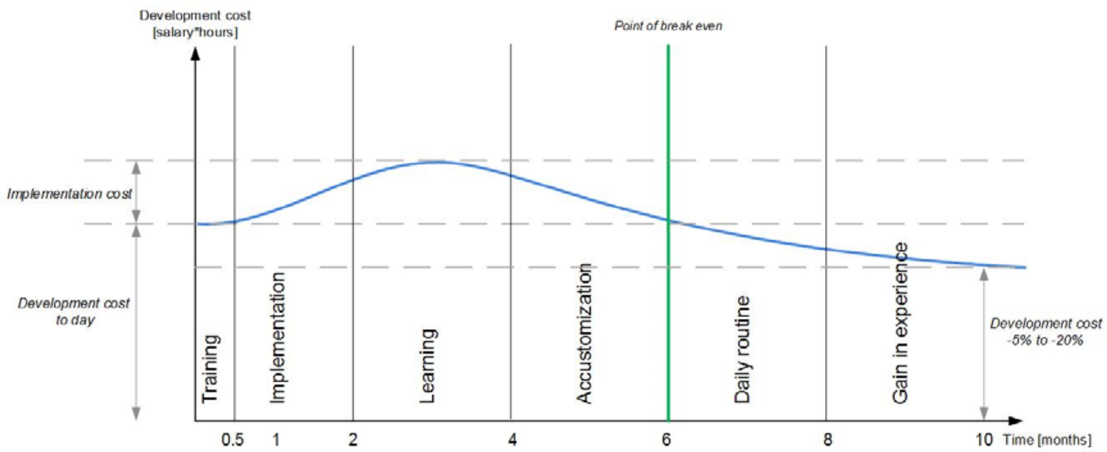

Figure 3: Illustration of the cost and time for a TWWD implementation.

The numbers in figure 3 has not been possible to verify. It is based on how the design engineers interpret the development lead-time and the flow of the design work. Also, figure 3 only describes the gain in development lead-time. The major gain are interpreted to be obtained in design quality and the output from the design work. The increased quality (less defective products at customers, or less defective manufactured parts) are also difficult to quantify, specifically since not all companies measures the design quality as such. The time to introduce new employees in the design work is also an obvious improvement. A clear and defined design process decrease the time it takes for junior design engineers to be up and running, and producing design solutions.

As an example on the value a defined design process, as TWWD, can be worth to a company. A design engineer working 1800 hours per year. If we assume that the company gain 10% on a TWWD implementation, this equals 180 hours a year. 5 design engineers could then together do the same work as before but with 900 hours less work time. These 900 hours corresponds to a cost reduction of approximately 50 000 Euro/year (given a salary and overhead cost at 60

Euro/hour). If the lead-time reduction is 20%, it will correspond to a cost reduction of approximately 100 000 Euro/year for 5 design engineers.

In addition to gains in design lead-time and design costs, there are more profits with the company's internal processes to make. Downstream in the production process, defective design solutions has a negative impact on different processes. The defective design solutions typically occur in incorrect detail design, or in drawings that will affect manufacturing and assembly. TWWD gives clear guidelines for how to design parts properly regarding the other departments' requirements and how the design work itself shall be performed.

For the management team of the company, it is safe, and a marketing advantage, to know that the development of the products is carried out in a specific and defined way – the company´s way. It is also something that creates added value in relation to the company's customers; i.e. that the development of the products is carried out in a way that ensures proper quality (and not in different ways by individuals). In the long term perspective, TWWD will guarantee that it is the company that owns the process and knowledge of how products are to be developed. Also, by following TWWD, parts of the standard ISO 9001:2015 (ISO, 2015b) Quality management system is fulfilled. Specifically section 0.3.3, 5.1.2, 8.2.1, 8.2.2, 8.2.3, and 8.3. For the standard ISO 14001:2015 Environmental management system (ISO, 2015a), TWWD will support parts of the standard to be fulfilled. Specifically section 6.2.1, 7.3, 8.1 and A.8.1. This will further strengthen the management team to feel safe regarding the development of the products.

For design engineers, it is a security to follow a process that ensures that designed products are made in the right way. Hence, to know that you not forgotten a vital step of the design work. Design engineers at a medium and a large company says that it is the final design quality that will be the most beneficial results from TWWD. Hence, little or no design rework is needed. For projects and project managers, it is easier to get an overview and plan the work as the various steps (checkpoints) are known. This makes it easier follow up time and staffing. Making a budget and forecast for different activities becomes easier, and the accuracy of costs and deadlines increase. A design engineer in a project, for example, can notify the project manager that she is at checkpoint C3. This information provides details about what the designer has done so far, and what remains.

6 Discussion

The alert researcher notice that TWWD does not contain checkpoints that includes known design methods, for example concept selection methods as in (Pugh, 1991). Where in the TWWD should the design engineer work with concepts, DFMA, industrial design, or functions and means tree? Or even more important, were in TWWD are key issues regarding modular products taken care of? These are all important questions. It is believed that if any company shall be able to incorporate different types of design tools and methods, or to develop a modular design, it will require and clear and defined process for how to design parts and products in the first place. TWWD is one contribution in order to set the base for a company´s product development process.

The objective during these years has been to develop the basic design process that can be applied to the product development companies. The checkpoints described in TWWD are all essential to a company, and can seldom be ignored. For example, to assure that the part are dimensioned correctly are essential to the company´s existence. But, how to generate and select concepts, for example as described in (Pugh, 1991) or (Ulrich & Eppinger, 2000), are not essential to a company. Based on the lean product development principles described in (Morgan & Liker, 2006), TWWD is one way to become a leaner product development organisation. Specifically on the Process part, see page 17 and chapter 3 and 4 in (Morgan & Liker, 2006).

The potentially next step would be to incorporate known design tools and methods at certain checkpoints. At least as an additional recommended way of working at a specific position in TWWD. Another area of improvement regarding TWWD is to identify measurements that can be used to follow-up and verify any improvements. Specifically this would be design lead-time, design cost, and design quality which is typical key performance measures.

Finally, in a time when more technological and digital things shall be designed into products (memory cards, sensors, Bluetooth functions, I/O modules, radio units, displays, etc.) it will be even more important that the baseline of how to design the products are defined and fully understood. Companies that we have been working with in research projects shows that one does not have enough routines for the design work. For example, they lack in their work for how to specify the design work, manage standards and directives, dimensioning parts, how to make CAD parts and assemblies, review drawings, making tests, or manage their documentation. These companies will have an even greater challenge to stay competitive now when products become more digital.

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