Chapter

An Approach to Improve the Product Design Process

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Abstract

The design work made by design engineers needs to be clearly defined and structured. The design process to follow should naturally lead to a systematic design work that reduces wasteful work, and reuses competence and knowledge from previous design work. 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 chapter 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 over more than 15 years. The process is built on 11 checkpoints (A to K), which gives details on the design process and is customized for the specific company. Implementations of TWWD in companies are described in this chapter, where the results have shown a gain in lead-time, development cost, and improved design quality.

Keywords: product design process, lead-time, design cost, design quality, design complexity

1. Introduction

Product design and its process have a major role in the competitiveness of a product developing company. Long development lead times will extend the market introduction of new products. Many design hours will incur high development cost, which in the end will increase the market price of the product. Unclear design specification and testing will result in an uncompetitive product. Design defects during the design work will cause the need for rework, and in the worst case, the end customer will have a defective product. Defective products introduced on the market will harm the company´s brand and market shares, as well as having a negative effect on the stock price. In the worst case, recalling the products or lawsuits will bring huge costs and negative media coverage for the company. See for example the summery made in table 5-3 p. 72 in [1]. Hence, a structured and effective product design process is essential for any product-developing company.

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, and a lot of software) 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 show 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, dimension parts, how to make CAD parts and assemblies, review drawings, make tests, or manage their documentation. These companies will have an even greater challenge to stay competitive now when products become digitalized, and even more demands are introduced into the design work.

Hence, the requirements of a structured and effective product design process will become even more essential due to digitalization than it has been so far. The whole product design process as well as the products will become more complex. Which put very new demands on the way the company develops their products.

2. Product design processes in general

The research regarding product design processes itself has been going on at least since the early 1960s when the work by [1] is commonly cited. Even though [2] 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. [1] stated 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 [2], which is known as the starting point of assembling researchers within the area.

Since the end of the 1980s, product development processes and methods have 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 [3–7]. These authors have made an important impact on the research community and the education of engineers at universities worldwide. Furthermore, in 2000, [8] launched their book product design and development which since has been renewed each 4th year. The book summarizes the work of other researchers and contributes to the concept development process.

At the beginning of the 1990s, modular design and product platform development emerged. However, companies have worked with modular product development since the 1930s. Scania, for example, initiated its modular development of truck components in 1939 [9]. IBM was a forerunner with their modular computer in 1964 when the System/360 was launched [10]. The underlying ideas regarding standardization and modularity started already in 1914 in the automotive industry [11]. One may even see Taylor's work in the early 1900s as a predecessor to both development processes and modularisation [12]. His ideas on standardized and repetitive work have analogies with today's reasons why companies develop modular products, for example, common units and carry-over modules, see [13]. Also, the work by [14] can be seen as one of the initiators of modular thinking. Modularisation has been part of many companies' way of designing products for the last 20 years. Many of them are described in Refs. [11, 13, 15, 16].

A comprehensive review of the available literature regarding product development processes is made by [17]. The one really interested in the wide range of processes; their work will guide further to a numerous of interesting literature. In [17], they classify different design and development process models into micro-, meso- and macro-level. Based on these levels, they also classify the design and development processes into procedural, analytical, abstract, and mathematical/computational. Their findings in [17], which one might agree upon, is that most situations for a product developing company require more than one category of model. In addition, the findings from reading their work, which they also conclude, is that the process should be built for its purpose. That is, the product design process should be made considering the company's needs.

During the last two decades, the lean product development (LPD) methodologies have been developed. Based on the lean manufacturing methods, as described in [18–21], lean product development aims at identifying wasteful design work and doing things as streamlined as possible. This has put a well-deserved focus on the design process. Some of the LPD work is based on, or inspired by [19, 21, 22]. As with lean manufacturing, LPD should identify and remove wasteful processes or activities, and follow certain principles. For example, [22] describes the lean way of Toyota which is built on three main areas; people, process and tools, and technology. Within these three areas, there are 13 principles to follow and apply to become leaner. Toyota is also the base for the book by [23] where the knowledge-based design are developed and described; which is another way of becoming a lean product development organization.

Different approaches have also been made to improve the design processes regarding specific areas. Improving the testing process and integrating it into the product design process [24] highlights some important factors to consider. For example, the design complexity, architecture, and novelty of the product, as well as the timing of the test itself. They conclude that it is important to depict testing more explicitly in the product design process.

To further improve the integration of industrial design and engineering design [25] looks into the potential ways of collaboration. In their work, foremost based on literature reviews and interviews, they propose a model for collaboration. They also mean that more concrete process models are needed for the specific company. How companies are working to improve the environmental impact of new product development was studied by [26]. Specifically, 10 companies were studied how well they have adopted ERM (environmentally responsible manufacturing) in product development. One of the outcomes of their work is that to design products environmentally friendly, the environmental aspects need to be considered early in the product design process.

3. Improvements in the product design process

During the work to develop The Way We Design (TWWD) and the implementations at companies, it is evident that despite the research and available literature on product development. Many companies still struggling to get a competitive product design process. The author´s own experience is that this depends on organic growth of company culture, just as described in [22], 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 better ways of designing things.

A lot of research has been produced within the area where [17] mentioned a lot of the literature. Still, models of different levels and abstractions are not made explicitly for industrial product design purposes. Within the research community, the challenges with product design and development processes are well recognized. Where one of the well-known journals within the area made a special issue on the topic. In that special issue [27] says that there is a need to continue to research the area of design and development processes since better processes will bring better products to the market and thereby increase profit to the company.

Furthermore, research indicates that the design work has a huge influence on the internal manufacturing and assembly processes, as well as the final product cost. Work by [28] concludes that there is little evidence of how much this influence actually is. However, the cost of the manufacturing and assembly process is partly a direct result of the design work. Here [29] 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.

The methods and processes available in the 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 a direct implementation at a company. In addition, available methods and processes assume that a new product shall be designed. While much of the design work at companies is just small changes in parts, drawings, or in part number structures. For companies, the time and work to change their way of doing things seems too long and undefined. As a result, the company and design engineers keep on doing things in the same (poor) way as before.

Also, it is not uncommon that the software design, electrical design, and mechanical design are working separately from each other, in their own way of designing. This occurrence can be seen in practice at three companies. Each of them even had separated group managers, which in turn had their own view on product design. When the products are embedded with all kinds of new technology, and the company goes from selling a product to offering a service, the product design process needs to integrate all key engineering functions to design a competitive (and complex) product.

Companies that suffer today from a poor product design process will have an even greater challenge to stay competitive in the future. Hence, when products become more digital, and more demands are introduced into the design work, the design process will be more challenging. As a result, the requirements of a structured and effective product design process will become even more essential than it has been so far.

Given the literature and examples discussed above, it is justified to develop a design process that is detailed enough for design engineers to understand and adapt 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 such as legalization and standards and be possible to monitor and manage during any design project. This design process should also make the design engineers work as an efficient whole, and not sub-optimize based on individuals. TWWD is one such design process that will contribute to improving the product design process.

4. The way we design process

The objective of the TWWD process, see **Figure 1**, is to provide a structured and efficient product design process ready to be implemented in an industrial company.

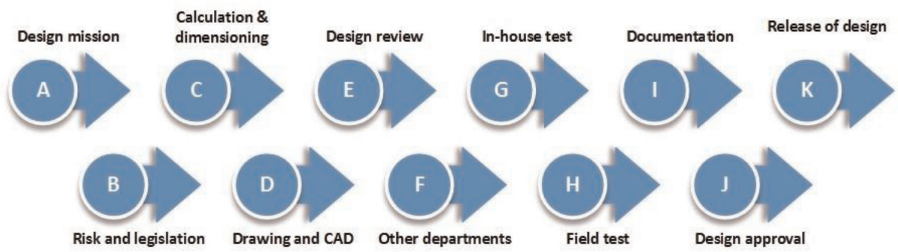

Figure 1.
The Way We Design (TWWD) process with K number och checkpoints.

The objective has also been to make it detailed enough so that each designers know what to do when following the process; but still a generalized product design process that can be implemented to a company. Most important; the objective with TWWD is a design process that will predict the outcome from the designer´s work and improves the R&D department's possibility to meet cost-, quality- and lead-time targets.

TWWD process needs to be owned and managed by the company, not by the individuals in the staff. Consequently, the knowledge of how to design the products shall be the core competence of the company. Therefore, as a part of developing the TWWD, continuous improvement and the management of the process have been considered.

The checkpoints in the TWWD process (A to K), see **Figure 1**, are essential to a company, and can seldom be ignored. Hence, the TWWD process is built on fundamentals applicable to any company.

5. The fundamentals of TWWD

TWWD process is built on four fundamentals: (1) checkpoints and the design manual, (2) documents and TWWD files, (3) the TWWD checklist, and (4) training material and TWWD management. Altogether, this builds up the TWWD process in a structured and efficient way.

5.1 Checkpoints

The first fundamental in TWWD is the checkpoints. The checkpoints range from checkpoint A (when the design work starts) to K (when the design work is completed), see **Figure 1**. Each checkpoint contains a question that needs to be considered by the designer, 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 an 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 (when answering **No**), the 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 to the design work in regard.

Each of the checkpoints A to K contains a set of sub-checkpoints, e.g. E1, E2, and E3, see examples in **Figure 2**. However, the day-to-day design work in the design of parts and products are unlikely to include all the checkpoints in the process. A major

Figure 2.
Checkpoint E and its sub-checkpoints.

part of the design work may be 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 describing TWWD. Nor do they necessarily move forward in a stepwise manner, checkpoint by checkpoint. As TWWD becomes implemented and familiar to the designer, the work is carried out in a smooth and lead-time efficient way. Then TWWD acts as the red-line and the base for how the designer shall design parts and products.

The checkpoints are not of equal magnitude and require a different amount of work to complete. In addition, the different checkpoints may be completed by different persons due to the nature of the checkpoint. The sub-checkpoints are arranged so that each sub-checkpoint (e.g. B1, B2, B3, etc.) can be completed by the same person. That is, risk assessments in B can be made by one person(s), while calculations in C are made by another person(s). Furthermore, to complete the design reviews in E might not be the same person(s) as performs the field tests in H. Hence, each checkpoint is characterized by a certain engineering skill.

Altogether, the checkpoints in TWWD are arranged based on the systematic nature of the design work, and the involved personnel required to complete the checkpoints and sub-checkpoints.

5.2 Checkpoint example—checkpoint E4: electrical design review

The complete TWWD process contains 11 checkpoints and 120 sub-checkpoints. These are not possible to describe in this chapter. However, for the reader to be able to follow and understand the rest of this book chapter, sub-checkpoint E4 is here written in its complete just as is written in the TWWD process.

5.3 Sub-checkpoint E4

An electrical design review is made to assure that the electrical design work and the designed parts and components are made correct. Always make an internal design review for work that is considered costly or comprehensive. Personnel who is part of a general design review meeting is the designer, an experienced R&D college, and personnel at other departments relevant for the review. The designer in charge of the design work assembles the personnel to perform the design review.

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Checkpoint question: Is an electrical design review completed?
To answer yes to this checkpoint:

- The designer shall send out drawings and/or material at least 2 working days ahead of the planned review meeting.
- The designer shall assemble suitable personnel for a general design review meeting.
- The designer shall present the designed part and its performance using drawings or 3D models, electrical schematics, or prototypes.
- When applicable, the designer should present several possible solutions (concepts) and together with the attending personnel select the best possible solution.
- The designer shall secure that the design fulfills the design specifications and performance (set in checkpoint A).
- The designer shall, based on the design review, make suitable adjustments to the part or design.
- Is the material/standard component available for the factories in China (or other preferable countries)?
- The designer shall document the general design review meeting using the TWWD review template in the TWWD files.
- The designer shall file the document according to documentation requirements.

5.4 Checkpoints and a good enough design

To overwork, the design of the part or product is not value-adding for the customer or the company. If the design is too poor, this will harm both the customer and the company. The design of the part and product shall be good enough, see **Figure 3**.

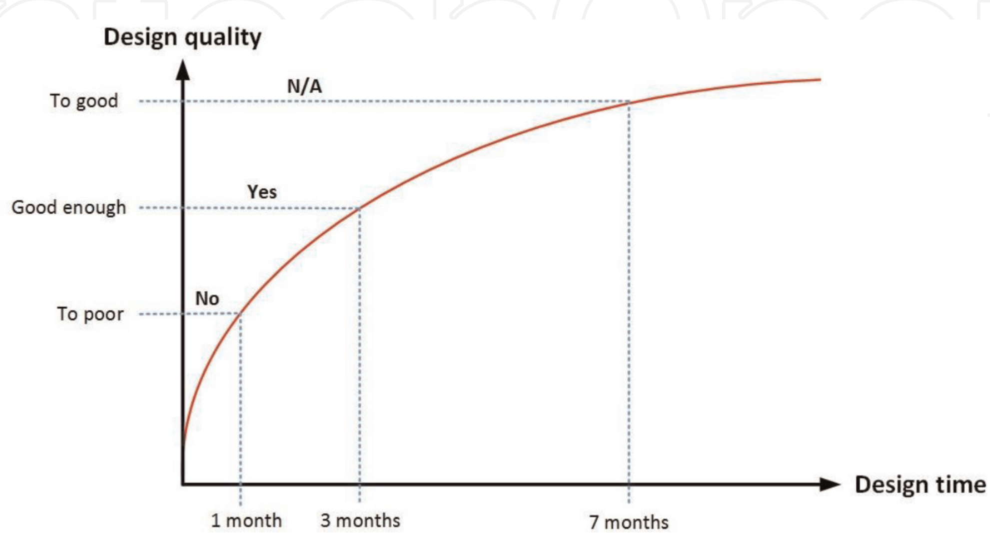

Figure 3.
A good enough design and the answers to the checkpoints in TWWD.

Good enough means that the product fulfills all demands from legalizations, standards, directives, customers, and our company-specific requirements, not more and not less.

The design quality graph in **Figure 3** illustrates the idea that it is not a linear relationship between design quality and design time. At some point, the quality improvements are not worth the effort in hours. The quality improvements are not possible to charge the customer, and the customer is not asking for this additional quality. For example, twice the needed life length of any given product. As a result, the design work needs to target the right quality for the right cost, which the customer is asking for and is willing to pay for.

The answers to each checkpoint in TWWD (N/A, Yes, and No), will support the design work to be good enough. If a checkpoint is answered No, the design quality will be too poor (since the checkpoint should be completed). If a checkpoint is answered Yes, the design quality is good enough (since it is necessary to complete the checkpoint). If the checkpoint is answered N/A, we have avoided that the design quality would be too good (since the completion of a N/A checkpoint would create an overworked design).

5.5 The design manual

In addition, as the first fundamental in TWWD, the design manual describes all checkpoints and how to complete them. The actual manual is a company-specific document that describes the checkpoints and how to complete them. The "company-specific" refers to the unique description of each checkpoint and the unique way to complete each checkpoint for the specific company. Hence, TWWD needs, to some extent, to be customized for the specific company and their "The Way We Design". The design manual is a digital document stored at a specific place according to the documentation requirements; and/or a physical booklet was given to each designer in order to simplify its compliance during the day-to-day design work.

The results by following the design manual shall be documented (checked) in the TWWD checklist for each completed design work. The results shall also be documented according to any specifications at each checkpoint, and according to the documentation requirements at the company. It is the designer's, or the involved personnel's, responsibility to answer and complete the checkpoint based on the best possible judgment and after performing as good as possible for the specific checkpoint. It is understood that all designers perform as good as possible and with the best possible judgment. After all, they have been employed at the company based on their engineering skills and personality. Hence, they are entrusted to have a good judgment and to follow the TWWD process and the design manual.

The designer shall not overwork each checkpoint or make it more complicated than it is. On the other hand, do not try to complete each checkpoint as fast as possible and jeopardize quality, performance, and total design lead-time (since the design may need rework if things go too fast which results in a design error). If something in TWWD is not clear, the designer needs to discuss this with the colleague or manager. If something in TWWD shall be overruled, the designer needs to discuss this with the manager for decision and action; or with the personnel that has the authority to decide on the specific checkpoint.

5.6 Documents and TWWD files

The second fundamental in TWWD is the documents and the TWWD files. There are many reasons why documents, templates, and the management of the documents 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 [30]. 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 to store, maintain, and reuse knowledge gained during the design of parts and products.

In checkpoint I, TWWD manage documents, as well as documentation requirements for each document. The TWWD files are the name of the folder system for all TWWD documents. The TWWD files contain the support documents needed for the TWWD process at specific checkpoints. Some companies store documents in many different locations, including local at individual designers' hard drive, as well as in SmarTeam or other PDM systems. During the last few years, SharePoint has become a commonly used base for document handling in the industry. However, the most important is to agree on where and how all documents shall be approved and stored.

5.7 TWWD checklist

The third fundamental is the 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 at checkpoint K, the checklist is stored according to the documentation requirements. 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 the TWWD checklist. As well as each designer in a project can tell where in the design process he or she is, and what remains before the release of the design in checkpoint K.

5.8 Training and management

The fourth fundamental in TWWD is the training material and management of the process. To train the designers and personnel at other departments in the company, a training material should be developed. The design manual together with a set of powerpoint sessions serves well as the training material. This training material describes and explains the different parts of TWWD. This is important, as a part of continuous competence development inside the company, as well as to train new employees.

Finally, the R&D manager (or the assigned person) shall be responsible for the governance and continuous development of the TWWD process. To this person, other personnel can submit suggestions for improvements to the company's TWWD. The TWWD manager will manage the process and is responsible for its maintenance, major updates, and that the process is followed including arranging training sessions. The R&D manager can delegate the responsibility and management of the process when TWWD is becoming the regular way and the designers are fully adapted to the process. Then the TWWD management can be delegated to another suitable person for the continuous support and maintenance of the process.

It is important that the designers contribute to developing TWWD for the company by bringing forward things that work poorly, and things that they believe are missing. Specifically, the designers should not hesitate to propose new and better things that can update TWWD. The company should continuously improve TWWD; this will give better prerequisites for the company to be even more competitive. Specifically, after completing checkpoint K, the designer is asked to document any improvements for TWWD and submit this information to the TWWD manager at the company.

6. Concurrent set up of TWWD

One important thing to accomplish short lead times in product design is to work and complete the activities concurrently. Here, the term concurrent is used but also the term “integrated” or “simultaneously” are widely used terms. The overall meaning is that things are done at the same time, in parallel, instead of in a serial pattern. The concurrent way to work has been known for decades to be a good way of planning and completing different activities. The concurrent work to design a product and its production system is thoroughly described in [31]. Their pioneering way to describe the ideal integration of design and production is aimed at better handling the increased complexity of manufacturing, competitiveness, new technologies, and the actual product and its design. Another pioneer within the concurrent set-up of work tasks is the work by Andreasen in [32]. Specifically, he describes the benefits and ways to integrate the areas of market, product, and production. Andreasen argues that product development cannot be made in the best possible way without integrating different areas of specialization. It is easy to agree on this, for example, that different ongoing product development projects need to integrate with each other. Alternatively, that different people with different responsibilities within a company need to agree on the best possible solutions. Hence, just focusing on increased assembly efficiency is not the only important thing when designing the product. Even though the work by [31, 32] was written more than 30 years ago, the concurrent way of working is more valid than ever. Hence, a company needs to be as efficient as possible in whatever they are doing. Today, concurrent design is widely used[1] by both researchers and practitioners to increase the efficiency of the design process and activities.

To optimize the lead time in TWWD, the checkpoints should be completed concurrently, when possible. The illustration of the TWWD process in **Figure 4** shows that the design work is performed by starting at checkpoint A and then finalized in a consecutive way onwards through the checkpoints. Checkpoint A is completed before starting checkpoint B, and so on. Note the importance, the process is designed and illustrated in such a way that each checkpoint is the last point of completing the design

[1] A search at google scholar on “integrated product development” will reveal 1,6 million hits. Since 2018, more than 50 000 text on the subject has been produced. Applied at a wide range of business and research areas.

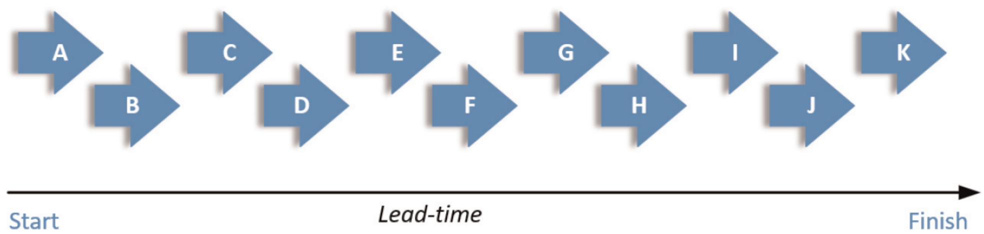

Figure 4.
Illustration of the TWWD process. The design work is performed by starting at checkpoint A and then finalized in a consecutive way onwards through the checkpoints. The checkpoints denote the last point of completing the work.

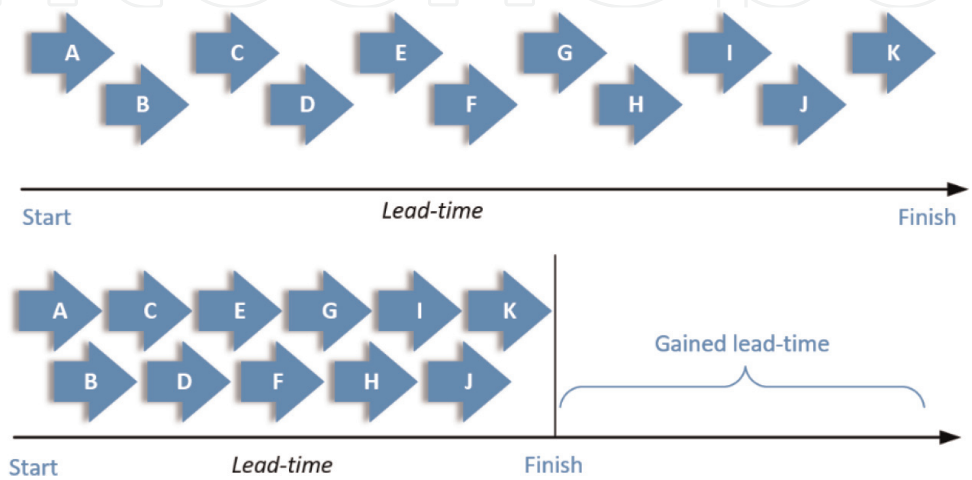

Figure 5.
The planning and the completion of TWWD will gain in lead time when the checkpoints are concurrently completed.

work. Hence, the checkpoints, and sub-checkpoints in the process denote the last point in time when the checkpoint should be completed.

Concerning the illustration in **Figure 4**, to optimize the TWWD process and design work, one shall plan the work so that less time (or no time) is spent on idling between the checkpoints. Practically, that means the designers and project manager carefully plan the design work so that any handover to other designers, as well as the startup of the next checkpoint, are made at the very best possible time. In this way, as illustrated in **Figure 5**, lead time will be gained.

In the upper part of **Figure 5**, the original illustration of the process shows that there is a gap (idle time) between the checkpoints. In the lower part, the TWWD process is compressed by having a well-planned process. In the lower part of the figure, each checkpoint is completed concurrently and handed over in a time-efficient way. At the end, a well-planned process will gain in lead time, compared to a process that is poorly planned.

For a specific checkpoint, for example, checkpoint B, not all sub-checkpoints may be needed for the specific design work. Hence, some sub-checkpoints can be removed based on the nature of the development project and the design work required. In addition, each of the sub-checkpoints may be integrated with each other to decrease the lead-time in the design work. Removing the sub-checkpoints that, for sure, is not part of the design work will then reduce the design lead-time.

As a result, of a well-planned TWWD process, one may identify, already from the start, which checkpoints can be removed from the process. In **Figure 6**,

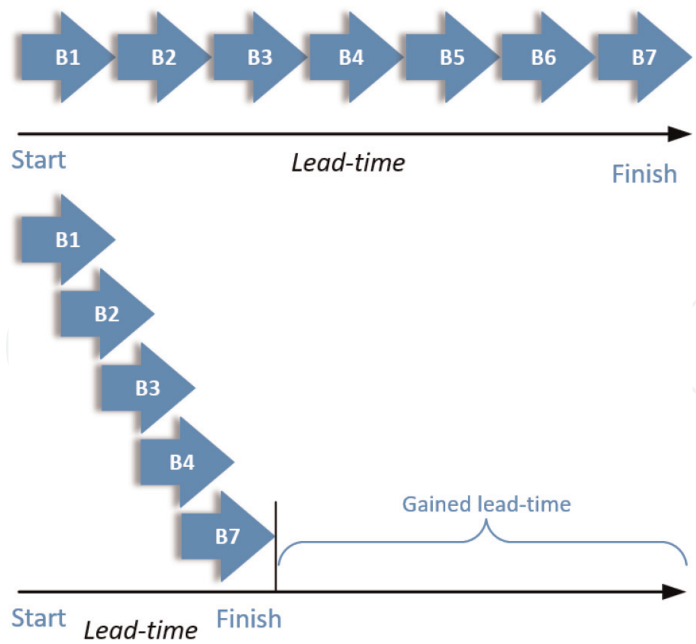

Figure 6.
Removing sub-checkpoints that will not be part of the design work, as well as integrated each sub-checkpoint will reduce the lead-time for each checkpoint.

sub-checkpoints B5 and B6 have been removed from the design work. In the same figure, the sub-checkpoints have been integrated with each other. Meaning that each sub-checkpoint is started before the previous sub-checkpoints are finished. Specifically, this is possible to accomplish when different design engineers are involved in completing the sub-checkpoints. In the end, further gains are made in shortening the lead-time in the design process.

6.1 Structuring the concurrent work in TWWD

Planning, compressing the design work, and integrating the work activities will bring gains in lead-time. To further optimize the design work in TWWD, one should identify dependencies and relations between the different checkpoints. As well as structuring the checkpoints in the most suitable order for completion. One way to do this is to use the design structure matrix. The design structure matrix (DSM), as described in [33–35], is a good way to structure the design work. The DSM was originally described in [36]. The article shows how DSM be applied to organize the design work and how to accomplish an effective development plan. Specifically, to identify and analyze the dependencies in a development plan. By doing this, one can identify possibilities to restructure the design work and thereby reduce the lead-time as much as possible.

At the very start of TWWD, it is the project manager, or any other that will manage the design work in TWWD, that will plan the order for the completion of the checkpoints. Depending on the company, product, and design work, this plan will be different for each of the design projects. In the DSM for TWWD in **Figure 7**, each checkpoint is structured in consecutive order. Just as illustrated in **Figure 4**, the next checkpoint is started when the previous is completed. In the matrix, the rows are the checkpoint to complete. The columns are the checkpoint that is required to be completed before the next checkpoint in regard can be started. The “X” in the DSM marks

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Checkpoint required as input (columns); Checkpoint to complete (rows)

	A	B	C	D	E	F	G	H	I	J	K
A	X										
B	X	X									
C	X	X	X								
D	X	X	X	X							
E	X	X	X	X	X						
F	X	X	X	X	X	X					
G	X	X	X	X	X	X	X				
H	X	X	X	X	X	X	X	X			
I	X	X	X	X	X	X	X	X	X		
J	X	X	X	X	X	X	X	X	X	X	
K	X	X	X	X	X	X	X	X	X	X	X

Figure 7.
Design structure matrix for TWWD. Without any restructuring of each checkpoint.

this relation and indicates which column (checkpoint) need to be finished before the next row (checkpoint) can be started.

As shown in **Figure 7**, the baseline for TWWD indicates that B cannot be started before A is completed; C cannot be started before A and B are completed, and so on. However, by planning for each product design project and restructuring the work, one may further cut the design lead-time and complete each checkpoint as just at the right time. In **Figure 10**, the DSM for TWWD is illustrated. The DSM is arbitrary but still a typical situation when checkpoints are restructured based on the actual opportunities in the product design work. In the DSM, no field tests are required so checkpoint H is removed.

In addition, the documentation required to complete checkpoint I does not need input from checkpoints F, G, J, or K. As a result, checkpoint I is restructured to be completed after checkpoint E.

The DSM in **Figure 8** shows another example where there are several spots where there are no dependencies. For example, any work is not required in checkpoint K until J is completed. For the project manager, to develop a DSM for the project ahead, it is a support to staffing the design engineers to the right work activity at the right

Checkpoint required as input (columns); Checkpoint to complete (rows)

	A	B	C	D	E	I	F	G	J	K
A	X									
B	X	X								
C	X	X	X							
D	X	X	X	X						
E	X	X	X	X	X					
I			X	X	X	X				
F	X	X	X	X	X		X			
G	X				X		X	X		
J					X	X	X	X	X	
K									X	X

Figure 8.
An example of a DSM where some independencies have been identified. Checkpoint H, field tests, has been identified as not required. Therefore, checkpoint H is not part of the DSM. As well as checkpoint I has been restructured and can be completed after checkpoint E.

Checkpoint to complete \ Checkpoint required as input	B1	B2	B3	B4	B7
B1	X				
B2		X			
B3			X		
B4				X	
B7	X	X	X	X	X

Figure 9.
The design structure matrix applied at checkpoint B. In this example, checkpoints B5 and B6 are not required for the design work in regard. In addition, B1 to B4 are independent of each other.

time. Specifically, this is useful when the design engineers are enrolled in several projects at the same time.

The DSM can be applied at each checkpoint as well. To exemplify this, in **Figure 9** a DSM has been made for the completion of checkpoint B. For the specific product design work in checkpoint B, checkpoints B1, B2, B3, and B4 can be made simultaneously and independent of each other. In its DSM, this is indicated by no X-marks in the intersection of rows and columns between B1 to B4. However, B7 cannot be completed before all other sub-checkpoints are completed. The DSM for checkpoint B shows that there is an opportunity to complete B at a relatively short lead-time. This is given four design engineers available, that can work on each of the sub-checkpoints simultaneously.

7. The starting point of TWWD

When is then the starting point of TWWD then? As one may have noted, TWWD starts with checkpoint A—the design mission, see **Figure 1**. TWWD is a product design process, meaning that it does not by far cover all parts of the product development process. TWWD starts when the product design mission is set. As illustrated in **Figure 10**, comprehensive work is assumed to be completed in the product development process before the start of checkpoint A.

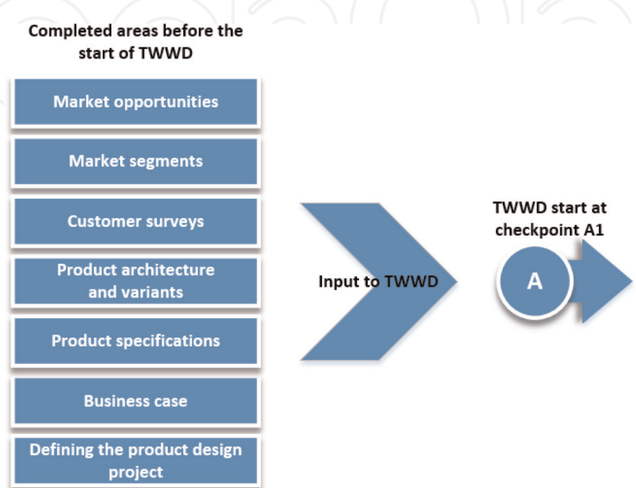

Figure 10.
The areas and work assumed to be completed before TWWD; and are given as input to the start of TWWD in checkpoint A.

For example, the opportunities the company have identified by launching a new product; or any segmentation of market and users have been completed. Also, customer surveys and needs have been identified; as well as any specific architecture and product variants have been set. The specifications for the product and its variants have been set (at least in overall terms). The business case has been identified including the target product cost. In addition, prior to the start of TWWD, the product design team has been identified and assigned to the forthcoming design work.

When the product design project is defined, then the design specification arrives at the design department who then will complete the actual product design. At this point, the TWWD will come into play and set off at checkpoint A1.

Worth mentioning, for some companies much of the product design work are for small upgrades and redesigns based on identified defects and errors, or planned upgrades. For these situations, TWWD can be applied at once and does not have to await all areas in the above figure to be completed again.

8. Improving the product design process in a vehicle electronics company

Several implementations of TWWD have been made in Swedish and Asian companies. In order to describe the implementation, work as well as potential gains, this section describes the actual implementation in a vehicle electronics company.

The work to implement TWWD was made from 2018 to 2021. Although the actual time for the implementation was approximately 18 months. The implementation was really challenging since there was a rather turbulent period for the company, as well as globally due to the Covid-19 pandemic.

The initiative for the TWWD implementation was a general need for being even better than today regarding product design and its lead-time and quality. The company has grown relatively much for some time, more design engineers are entering the company, as well as more and more product variants are offered to the market. The company´s R&D is built on electrical, software and mechanical design. The implementation team was initially seven persons and the R&D manager. Of which, there were two design engineers from each of the three engineering areas. An initial plan was made with the aim of having the implementation done in 49 weeks. The set-up for the teamwork meetings was that we met every other week where we discussed each of the sub-checkpoints one by one.

One of the first things that were done was to sketch an overview and description of the way the company manages documentation and the routines for who will review and approve the documents. During the discussion regarding the documentation, it was clear that this would be an important thing to improve the design work at the company.

After some months of work, the company purchased another company. This meant a change in the implementation team composition. New design engineers joined the team and others left the team. Hence, there was a need to get the new team members up to date with the work so far. This was done by separate meetings with the new team members where the author tough the TWWD and explained the work so far. Still, we were working as a cross-functional team with design engineers from all three areas. At these meetings, the R&D manager participated, as well as key persons from software-, electrical- and mechanical engineering.

Specifically, during the implementation work, it was clear that there were three separate minor development ways at the company. One way for electrical design, another for software design, and a third way for the mechanical design. In order to fully understand these three ways, we had separate meetings with each of the three. At these meetings, it was clear that within all three areas, there were also individual ways of doing things. One of the biggest challenges was then to get all together and work similarly toward an efficient whole.

Another challenge at the company was that the complexity of the product made it rather difficult to manufacture. In addition, mechanics, electronics, and software had to work perfectly as an entire. Due to the use and the contents of the products, there are many regulations that the products should comply with. This further stressed the importance of being even better at managing documents, and the requirements for those.

Due to the continuous growth of the company as well as the newly acquired company, the implementation work was set on held. Approximately 6 months later the implantation work was back on track. Meanwhile, another company had been acquired, as well as even more growth in Asia. Yet again, new team members joined the TWWD implementation, as well as other left. There was also a new R&D manager in place. The new R&D manager together with a new implementation team improve the work as well as the stress to get TWWD in place. Due to the rather turbulent period, the growth, and staff turnover, it was even more important to get a common way of designing products.

Well up and running again, a new and good way of working was developed. Before each meeting, the design engineers and the R&D manager really studied the forthcoming sub-checkpoint. As well as figuring out how the checkpoint relates to other know and good routines that should be kept and integrated into TWWD. In addition, the top management was encouraging the implementation to push through and to be finalized. With the rather new way of working, each implementation meeting was fast and fruitful and we could focus only on the actual tuning the sub-checkpoints in regard.

Just as we were about to reach checkpoint I in the implementation work, the Covid-19 pandemic hit Sweden hard. As for most of the companies around the world, orders went down, and personnel were sick as well as working at home. The company put the implementation work again on hold. We did a few attempts to start up again, but we were put on hold. New ways of having meetings through Microsoft Teams or other video conferencing software made it possible for us to get back on track again.

In November 2020, we started up the implementation work through video conferencing, now, with a smaller group of attending design engineers. We rescheduled the implementation several times and we had a few more breaks during the final checkpoints. However, despite all challenges, we finally completed the implementation according to the implementation plan in **Figure 11**.

8.1 The investment cost

During the approximately 18 months of actual implementation work, there were an average of six design engineers, including the R&D manager being part of the work. On an average, the engineers worked two hours per week. This gives a total of 864 hours of work. At an hourly rate of 700 SEK, the total investment cost is 604 800 SEK.

8.2 Payback calculation

Among the benefits was that the early preparation stages before starting a project do have more substance, better confidence, and thus decreased risks of late and costly

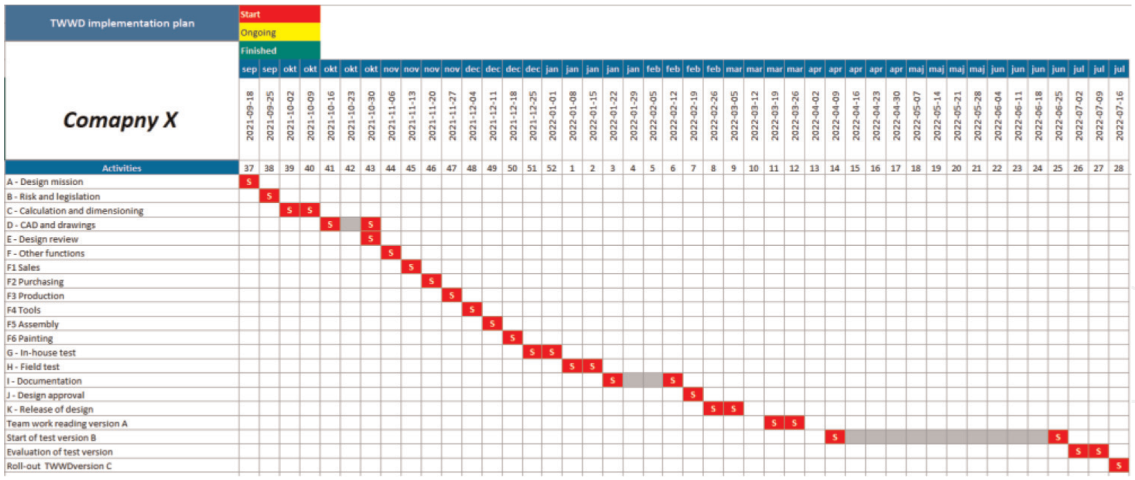

Figure 11.
The final implementation plan at company X (Vehicle Electronics Company).

change requests. In short, checkpoint A helps the company to be as ready as possible before starting the design work. Second, the obvious benefit of having a clear and structured way of working are to be able to see where the designers are working at, which checkpoint they are. Everyone knows what is expected from them, and engineers can work in the same way. Third, the company´s documentation is more structured and harmonized which makes them work according to standards and legislations, as well as being able to store and maintain the knowledge among the personnel. In total, the company sees a general increase in efficiency in several areas.

Based on the implementation work, the company forecasts a decreased design lead-time of at least 10%, probably more. This is mainly due to reducing the number of reworks among the engineers. At the company, there are 60 design engineers that have 108 000 work hours annually. At an hourly rate of 700 SEK, this equals a personnel cost of 75 600 000 SEK. A decreased design lead-time equals an annual cost reduction of 7 560 000 SEK or a decrease in personnel by six persons.

The numbers to use for the payback calculation are as follows:

- Reduced annual design cost: 7 560 000 SEK.
- Investment cost year 1: 604 000 SEK.

These numbers are inserted in the payback table, see **Table 1**, where the investment is made at year 1. In the following years 2, 3, and 4, the company will acquire the gains in design cost. At the end of a 4-year period, the accumulated cash flow is positive results of approximately 22 MSEK.

9. Conclusions

By structuring the design work and planning for the design process, gains will be made in design quality, lead-time, and cost. The design process TWWD has been developed and implemented in several companies for improving the design work. In the implementation case described in this chapter, the investments in improving the product design process will have a major positive effect on the product design years

Payback TWWD implementation	Year 1	Year 2	Year 3	Year 4
Investment cost	−604 800 SEK			
Cost savings in design		7 560 000 SEK	7 560 000 SEK	7 560 000 SEK
Total net cash flow	−604 800 SEK	7 560 000 SEK	7 560 000 SEK	7 560 000 SEK
Accumulated cashflow	−604 800 SEK	6 955 200 SEK	14 515 200 SEK	22 075 200 SEK

Table 1.
Payback calculation for the implementation at the vehicle electronics company.

ahead. Typically, the benefits are gained in lead-time and development cost, which have shown to be rather easy to calculate.

Even though TWWD has shown to be one approach to improving the product design process. There should be more cases of implementations before one can say that the process will generally work for any (many types) company. Also, there is still work to be done to better calculate the improvements in quality.

Finally, one may conclude that there is a need for companies to adopt a structured product design process (such as TWWD). Specifically, since the competitiveness also depends on the actual design process maybe more than ever.

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