THE DESIGN PROCESS

1 An Introduction

The Design Process is one of a number of subsets to an overarching Engineering Process. Below is an illustrated example demonstrating some of the other processes which tie in or fit under the Engineering Process header. There should be some form of linking between these sub processes in order to reduce work duplication and promote common interfacing.

To establish an efficient Engineering Process, a good understanding of each sub process is needed in order to limit work duplication and maximise process flow. The best approach is a holistic one realising that you aren't going to setup the perfect process the first time. Refinements are always needed to move toward the goal of a stable and reliable outcome.

In this example we will start with the Design Process as it is a process all engineering companies should understand. Like most processes, they are as complicated as the conditions you set upon yourself and no one knows what best suits your set of circumstances better than someone who is familiar with your business. It is a common approach to make processes rigid and all encompassing and soon you find yourself a slave to the very thing you created generating copious amounts of work in order to meet your own system requirements. It doesn't need to be this way, you are the one who sets the conditions you work to and this should be kept in mind.

In this guide we will cover a standard product to manufacture process without the creation of a physical prototype. This is obviously not the only process configuration out there but it serves to illustrate some key principles. Depending on your own needs you can choose to exclude steps, minimise the time spent on certain elements or fully expand upon each in order to provide the desired outcome. Each step should add benefit to the end goal and if it doesn't, why have it?

This example is set out for the development of a design sufficiently complex to demand the use of a formal process. Such a design would usually comprise of multi-disciplinary elements or systems. Single person design functions may borrow some useful elements laid out herein but overall the process would be considered excessive.

In this example, a three tiered approach is used to progress a design from concept through to manufacture. The process is based on a simplified systems engineering format and adaptions have been made with the benefit of personal experience. Three design stages are used in the process, these are:

1) Conceptual Design
2) Preliminary Design
3) Critical Design

These three phases represent a gradual broadening of the design effort. The Conceptual Design Stage brings about a design focus by establishing design concepts and culminating in the selection of a singular design configuration. The Preliminary Design Stage expands the effort by designing the higher level features of the concept. This stage allows a design to maintain its fluidity without resulting in the loss off too much time and effort should changes be required. At the end of the Preliminary Design Stage the design configuration should be quite well established leaving the Critical Design Stage to finalise the detail of each element right down to the highest level of intricacy.

2 The Design Concept Stage

In this stage, the need for a design is raised. This maybe as the result of a customer request, an internally generated design requirement or any other multitude of reasons. It is presumed that a preliminary vetting of the designs value to the business has been conducted as to not waste time on potentially unprofitable works. This may have been conducted by a sales team, product management board or other relevant party.

It is in this phase that a review of the design need is conducted and preliminary information on the task is compiled. A number of conceptual options are formulated to address the design requirement. In order to select the most viable solution, the concepts are evaluated against a list of key design success criteria which are also defined in this stage. The final outcome of this process is a concept solution tailored to the identified design need.

2.1 Need Identification

First you should identify the fundamental need for the design. This is the initial step in identifying "the problem/task" and one of the most important steps taught to any young engineer at university.

- Where does the need originate and with who?
- Is it client based, business based or otherwise?
- What documentation exists to demonstrate its origin?

2.2 Need Review

Next you need to identify the design need. Quite often the design need comes with a design suggestion or request. Here a gateway review needs to be conducted using the benefit of your skill and experience to assess factors of practicality, best design value and so on. You may wish to evaluate such questions as:

- Is the need as communicated actually what is required?
- Do solutions to this need already exist?
- Can your industry knowledge provide a better solution or design direction?
- Do alternatives or questions need to be fed back to the need originator for clarification?

2.3 Problem/Task Identification

You need to understand a problem in detail in order to achieve the best possible outcome. Consider this understanding the foundation of your design. It is common for people to head off on a tangent due to an improper understanding of the original problem. Again here are some prompts to help solidify the problem/task at hand:

- What is the request for?
- What documentation outlines the request detail?
- What are the battery limits of the design?
- What interfaces exist?
- What are the functional requirements of the design?
- What are the constraints that are impose upon the design?
- What are the life cycle operations that the design must consider i.e. operation, maintenance, overhaul etc.?
- Has a design like this been done in the past? If so what are the similarities and where can information be found?
- What are the key success criteria for a successful design concept? Cost, time, reliability, technical certainty etc.?

From the abundance of design possibility available, this information should provide you with the necessary conditions which allow you to narrow down your focus.

2.4 Conceptual Design Options

Now you need to formulate some design options and there are many ways of doing this. You can brainstorm amongst your team, employ defined methods of conceptualising or simply sit down on your own and think. Tailor the method to the design at hand in order to produce a desired number of solutions each ready for initial evaluation.

- What design options exist? Provide a number of roughly conceptualised options for evaluation.
- How do the features of these options address the problem/task definition criteria? Does a design address all relevant problem/task criteria?
- If assumptions are made in the composition of a design option, list these down so that they can be referenced at a later point.
- What are the pros and cons of each design option relative to the key design success criteria?

2.5 Design Concept Review (DCR)

This is the final phase of the Design Concept Stage. This stage entails the meeting of all necessary stakeholders in order to review the list of concepts generated within the earlier steps. This should be considered a design gate to be completed in full before further detailed developments begin. It is a good stage to gain broader feedback and involve all parties in the design.

- Review the pros and cons of each concept verses the key design success criteria. Which option is the most viable?
- What information is required to further progress this design and from who?
- What areas need to be investigated to ensure the design has a high degree of certainty?
- Are all the stakeholders happy with the assumptions that have been made?
- Select a concept for progression otherwise repeat the process until a suitable concept is formulated.

2.6 Summary

The detail provided in this section can lead to a large amount of work in order to simply generate a handful of design concepts. Of importance is the information gathered and not so much how it is formalised. Larger designs generally entail more stakeholders and a more in-depth and formal process. Small designs however can be addressed in a far more streamlined manner. Ask yourself the questions and generate the supporting paperwork as required. Larger processes can generate paperwork to tie in with a systems engineering approach or similar, while for smaller designs, meeting minutes may suffice.

3 Preliminary Design Stage

This stage is where the systems and subsystems of a design are detailed and formalised. In general, no detailed design is carried out at this stage past the point of a subsystem level. During this stage, all the mandatory and non-mandatory design requirements imposed upon the design are identified and listed for verification. A review is conducted on each system and subsystem to ensure they meet all the requirements of the final design. Following this process a list of rectifications and work requirements will be created to be closed off prior to the completion of the Preliminary Design Stage.

The Preliminary Design Review stage may need to be broken down into manageable forums. System and subsystem reviews may need to be conducted separately before a final integration is conducted. This final integration should be conducted as a Preliminary Design Review on the top level systems as a whole.

3.1 System and Subsystem Identification

Listing out your systems/subsystems is a good first step to allocating design responsibility. Usually systems are laid out in terms of discipline, function or purchasing package. It is easy to allocate a responsible party for each of these once identified.

- List out every system and subsystem
- Allocate responsibility for each of these systems/subsystems

3.2 System Function

Next each system is defined a function and interfaces are listed out between each system in order for these functions to occur. It is important to identify the interfaces as these become points of commonality between design packages. Though it may be a joint effort to develop the specifics of an interface, at this stage a single person should be identified as being responsible for this deliverable.

- List the function of each system and how each interfaces to complete the design.
- Identify and list each interface point between the different systems and allocate a responsible party for this design aspect.

3.3 Subsystem Function

As with a system, subsystems too need to be identified along with their interfaces.

- For each system, list the subsystems that exist along with their function toward the whole.
- Identify and list each interface point between the different subsystems and allocate a responsible party for this design aspect.

3.4 Project Plan

In the mix of identifying systems and subsystems as well as design deliverables, a full project plan needs to be compiled. The purpose of the plan is to stage out the sequencing of each design task or deliverable. This is often done using a list of milestones, each required in order to provide a defined design package. Using the package breakdown identified through the listing of each system or subsystem, start to add peripheral tasks to develop a comprehensive plan. This plan should clearly identify both the Preliminary and Critical Design Stages. Over the successive process steps adjust the plan as necessary in order to correctly capture the final agreed design function.

3.5 Design Requirement Identification

The next step is to identify all the requirements that have been imposed upon your design. These may come from external or internal specifications, contractual obligations or mandatory legislation. This example step is arranged in a systems engineering format in order to capture all possible deliverables, responsibilities and close out tasks. Systems engineering software is available to track all these variables however this often requires the employment of a person well versed in the systems engineering approach. For a lesser outlay, simple processes can be developed in house to perform a similar task. These methods are often better suited to lower levels of task traceability but can still prove very functional. It all depends upon your individual need and how much time you really wish to spend ensuring design compliance. Despite the appearance, this stage can be managed quite simply.

If a tender has facilitated the design need, a good starting point for this step is the compliance/Non-compliance matrix offered to the client during the bid. Tying in with this set of responses ensures a good basis for compliance management with both the needs of the client and your own tender commitments.

One task that should be performed during this stage is the allocation of a verification milestone to each deliverable. This should include at what design stage the deliverable will be assessed for fulfilment. This could be either at the Preliminary Design Review, Critical Design Review or both. It is important that you have an idea of how you plan to close out these items and with what deliverable.

- Collate and detail all design requirements, mandatory or not, that the design will adhere too.
- Allocate each design requirement to a system or subsystem.
- Allocate a verification milestone and method against each requirement
- Allocate a responsible person for the verification and sign off of each requirement.

3.6 Design Requirement Forwarding

Not all design elements are necessarily completed in house, some may need to be contracted out to third parties. For these elements you need to identify the design packages as well as the deliverables that result from each. By doing this upfront it makes the design task upon a third party clearer and more readily assessable. You may choose to develop a specification using these requirements in order to mandate certain deliverables.

- Identify all the components of the design that are to be allocated to third parties for supply.
- Ensure each design requirement is handed on in full to the third party through the use of commercial or specification documents.

3.7 Deliverables

After a clear understanding has been created of the preliminary design deliverables as well as the allocation of responsibilities, the design process can begin. Each system can now be designed in

greater detail by the people or companies tasked with the role. This may be the development of FEA models and validation of structural elements, hydraulic schematics for fluid power circuits, functional specifications, P&I diagrams for controls circuits and so on. The finer details of a design such as the development of detail drawings, the physical placement and exact specification of hydraulic components, programming of controllers, formulation of termination diagrams etc. should be left for the following design phase. This is because the design still has a level of fluidity at this stage and getting ahead of the process can lead to great time wastages if changes are required to an over defined design element.

3.8 Preliminary Design Review (PDR)

This is a scheduled event designed to close out the Preliminary Design Stage. At this stage the design has taken shape and is well defined in terms of its higher order functioning. During this period the different systems/subsystems are brought together and evaluated in terms of the whole following a standard design review methodology.

Complementing the design review is a close out of the design requirements for this stage. Verification information should be provided by all those tasked with a deliverable to demonstrate their compliance with each design requirement identified in Section 3.5.

- What is the system/subsystem the review is being conducted upon?
- What are the interfaces into and out of the system/subsystem?
- What are the design requirements for the system/subsystem?
- What additional design focuses can be applied to the system/subsystem? These may be for example:
  - Ease of operation
  - Manufacturability
  - Cost
  - Lead-time
  - Ease of maintenance
  - Ease of overhaul
  - Reliability
  - Lessons learnt from similar past design configurations.
- Review and assess the compliance of each aspect of the design with the design requirements as listed.
- Review and assess the design against the additional design focuses identified. For functional aspects of the design such as manufacturability, ease of maintenance, overhaul and operation, a conceptual walk through of each operation may be beneficial.

3.9 Preliminary Design Review Outcomes

Following the Preliminary Design Review, not all items may be closed out due to a need for rework or clarification. These items should be tabulated and corrective actions allocated to the responsible party. For design elements that are complete and verified, these can be signed off.

3.10 Preliminary Design Close Out

For any rectification work, verification of the updated design component is required in accordance with the previous PDR criteria. Once all verifications have been achieved, the Preliminary Design Stage can be closed out.

3.11 Summary

The Preliminary Design Stage provides the broader design base used to fill out the finer details. This stage also sets out the design deliverables, project plan and a means for measuring design compliance against all agreed design objectives.

4 Critical Design Phase

This stage is where the bulk of the detail goes into a design. Each subsystem is rounded out in full and finalised in the form of ready to manufacture/release information. This information may include detailed shop drawings, completed electrical schematics, maintenance manuals, quality documents, test procedures and so forth. Culminating this stage is a review of all this information. This review takes place in order to ensure all works comply with the agreed design requirement. Once the design has been checked and validated this phase is closed off and the design is ready for issue.

4.1 Critical Design Review (CDR)

As with the Preliminary Design Review, a series of formal assessments are made regarding the work conducted during the Critical Design Stage. These reviews focus on the detail of the works in order to ensure the finalised design is functional and achieves the level of quality envisaged.

- What system/subsystem is the review being conducted upon?
- What interfaces are relevant to the system/subsystem?
- What are the design requirements for the system/subsystem?
- What additional design focuses can be applied to the system/subsystem? These may be for example:
    - Ease of operation
    - Manufacturability
    - Cost
    - Lead-time
    - Ease of maintenance
    - Ease of overhaul
    - Reliability
    - Lessons learnt from similar past design configurations.
- Review and assess the compliance of each aspect of the design with respect to the design requirements. Pay attention to the marrying up of interfaces across different subsystems.
- Review and assess the design against the additional focuses identified. Again for functional aspects of the design such as manufacturability, ease of maintenance, overhaul and operation, a conceptual walk through of each operation may be beneficial.

4.2 Critical Design Review Outcomes

For the elements of the design that are complete and verified at this stage, these can be signed off.

For the elements of the design that require rework, these need to be tabled and corrective actions allocated.

4.3 Critical Design Close Out

For any rectification work, verification of the updated design component is required in accordance with the previous CDR criteria.

Once all verifications have been achieved, the Critical Design Stage can be closed out.

4.4 Summary

This phase represents the bulk of the design detail to be performed. It builds upon the work of the Preliminary Design Stage and brings to a close the design effort needed to start the production of an item. Engineering effort and design feedback are still required past this point as issues with the design detail and various other functional aspects of the designs production will invariably arise. This component of the process has intentionally been omitted from this example and is left for further discussion.