

Appendix B: Realising Innovation, a Systems Approach

Factors in the systems engineering field influencing the realisation of an invention may be categorised in the following manner. They directly influence the timing and success of innovation and therefore form a crucial part in the life cycle of an innovation.¹⁵

B.1 Conceptual System Design¹⁵

The requirement for the success of any system or product is acceptance and demand in the market. System requirements form a key part in identifying exactly what the product needs to accomplish, and deliver to the client. In the conceptual design phase emphasis falls on defining of system requirements such as market need, project feasibility, system operational requirements and finally system maintenance concepts.

The conceptual system design phase, in essence try to define the complete scope of the product and the tasks associated with realising it in the market.

B.2 Preliminary System Design¹⁵

The technical baseline as defined by the previous stage, forms the starting point of preliminary systems design.

System functional analysis is one of the essential aspects of a new system, for it highlights design requirements in a hierarchical way. As a systematic approach to system design, functional analysis constitutes the process of translating system operational and support requirements into specific design requirements. As such it is intended to facilitate design, development and definition in a logical manner.

Allocation of requirements relates to the assigning of resources to proposed new systems. Systems can be broken down into their different categories and components, each of which needs to be allocated certain resources. It is therefore necessary to first establish requirements at the systems level, and then allocate requirements to the depth necessary to provide guidance in the design process.

In any design or new innovation, many trade-offs and optimisations are made. Parameters of primary importance at the systems level include cost effectiveness, system effectiveness, logistics effectiveness, life-cycle costs effectiveness, operational availability, and performance. These parameters should relate directly to the problem statement. The objective of course is to arrive at a decision where the selected approach is clearly the best among the alternatives evaluated, with the associated risk and uncertainty minimised.

With the allocation of requirements and definition of optimised direction, a synthesis of elements is required. System synthesis can be achieved when sufficient trade-offs and preliminary design have been accomplished to confirm and assure the completeness of system performance, and design requirements allocated for detail design.

In conclusion a system design review concludes preliminary system design. At each major stage of the design process, an evaluative function is accomplished to ensure that the design is correct at that point, prior to proceeding to the next stage.

B.3 Detail Design and Development¹⁵

The detail design process comprises the description, preparation, definition development and testing of all aspects of the system. A high degree of documentation and specification is needed to ensure all aspects are designed and developed appropriately, as well as tested thoroughly.

Detail design requirements

Detail design requirements need to comply with all previously specified documentation in the conceptual and preliminary design phases. Some other key areas in the detail design phase include:

Design for functional capability or performance (functional design) — the characteristic of design that deals with the technical performance of the system. This includes size, weight, volume, shape, accuracy, capacity, flow rate, speed of performances, power output, and all of the technical and physical characteristics a system should exhibit to accomplish its planned mission.

Design for reliability — the characteristic of design and installation concerned with the successful operation of the system, throughout its planned mission. A common way of measuring this is the MTBF (mean time between failure) method.

Design for maintainability — the characteristic of system design and installation that is concerned with the ease, economy, safety, and accuracy in the performance of maintenance functions. The objectives include minimising maintenance times, maximise supportability characteristics, as well as logistic support resources required for the maintenance.

Design for manability — the characteristic of system design that is directed toward the optimum human-machine interface. Human factors that need to be considered are operational and aesthetic features as well as personnel skill, level for operation, training requirements, and minimising potential personal error rates.

Design for producibility — the characteristic of system design that allows for the effective and efficient production of one or a multiple quantity of items of a given configuration. The objective is to minimise resource requirements during the production or construction process.

Design for supportability — the characteristic of systems design, directed towards ensuring that the system can ultimately be supported effectively and efficiently, throughout its planned life cycle. An objective is to consider both the internal aspects of equipment design, as well as the logistics needed for support.

Design for economic feasibility — the characteristic of system design and installation, which is directed toward maximising the benefits and cost effectiveness of the overall system configuration. An objective is to base design considerations on life-cycle cost, and not just on system acquisition cost or purchase prices.

Design for social acceptability — the characteristic of system design directed towards ensuring that the system can become an acceptable part of the social system. An objective is to seek minimum pollutability, ease of disposability, minimum safety risk, high transportability, and many others.

The above-mentioned considerations are but some of the areas of importance in the field of detail design. Ultimately the satisfaction of the client regarding cost, quality and performance is the key in successful detail design.

Technical performance measures

Technical performance measures refer to design-related factors expressed quantitatively, which can be applied in the evaluation of a system or one of its components.

Cost-effectiveness relates to the measure of a system in terms of mission fulfilment and total life cycle cost. It can be expressed in various terms, depending on the parameters one wishes to evaluate. As such, true cost effectiveness is impossible to evaluate, since many factors influence the operation and support of a system, which cannot be realistically quantified. Some common figures of merit (FOM) used are:

$$\text{FOM} = \frac{\text{System benefits}}{\text{Lifecycle cost}}$$

$$\text{FOM} = \frac{\text{System effectiveness}}{\text{Lifecycle cost}}$$

$$\text{FOM} = \frac{\text{Availability}}{\text{Lifecycle cost}}$$

$$\text{FOM} = \frac{\text{System capacity}}{\text{Lifecycle cost}}$$

$$\text{FOM} = \frac{\text{Supply effectiveness}}{\text{Lifecycle cost}}$$

By presenting these and other factors for alternative designs, a realistic comparison can be made. Given two or more alternatives based on these values, the best can be selected.

Detail design activities

Once the goals and objective for the detail design process have been established, a design team is appointed. Such a team needs to consist of all role-players as proposed by the concurrent engineering design approach.

Establishing a design team

Due to the nature of projects and innovation, every design team will consist of different people and disciplines. A typical design team may include a combination of:

Engineering technical expertise — electrical engineers, mechanical engineers, computer engineers, civil engineers, nuclear engineers, system engineers, reliability and maintainability engineers, logistics engineers, and/or others appropriate to the projects.

Engineering technical support — draftsmen, technical publication specialists, component-parts specialists, laboratory technicians, model-builders, computer programmers, test technicians, and the like.

Non-technical support — marketing, purchasing and procurement, contracts, budgeting and accounting, legal, industrial relations, and many more.

Proper integration and good motivation are crucial to the success of the design team. An organisational goal, project organisations, functions and tasks and associated management of project resources, need to be properly managed and controlled.

Evolution of detail design

The design process is iterative and can be better illustrated with a flow diagram. The process starts at the system specification level, and progresses to an output that can be produced in single or multiple quantities. Checks and balances in the form of reviews at each stage ensure conformity to specifications, with the added feedback loop for corrective action [Figure B.1].

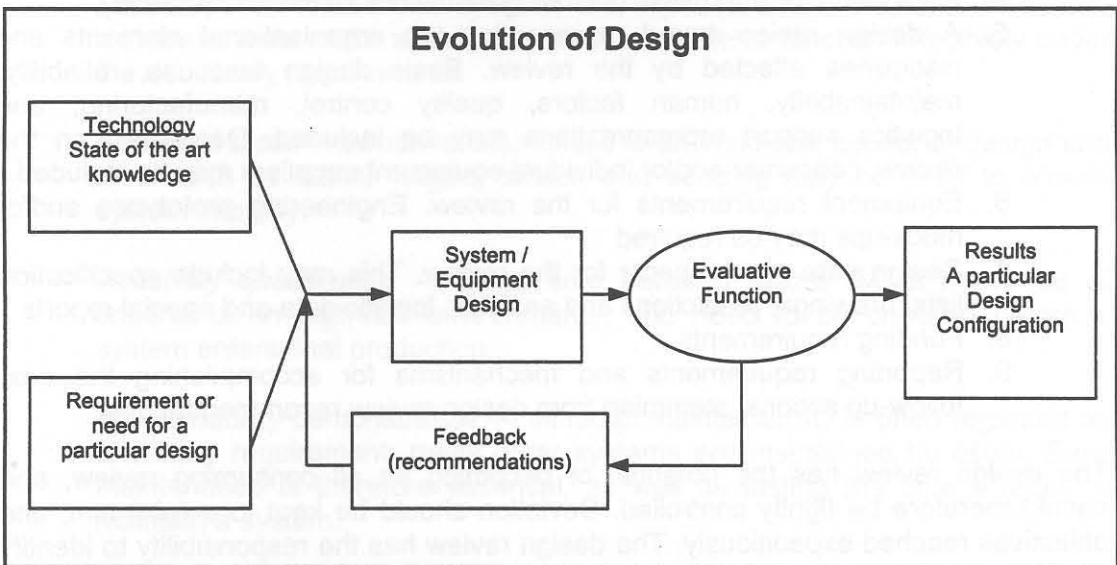


Figure B.1: Evolution of Design adapted from Blanchard and Fabrycky¹⁵

As detail design progresses, actual definition is accomplished through documentation, in the form of specifications and plans, procedures, drawings, material and part lists, reports and analyses, computer programs, and so on. Design documentation is absolutely critical, since people other than the design engineer should be able to check and understand the reasons behind every design output.

Traditionally design documentation consists of a combination of the following:

Design drawings — assembly drawings, logic diagrams, installation drawings, schematics, and so on.

Material and part lists — part lists, material lists, long-lead item lists, bulk-item lists, provisioning lists, and so on.

Analysis and reports — trade-off study reports supporting design decisions, reliability and maintainability analysis and predictions, human factor analysis,

safety reports, logistic support analysis, configuration identification reports, computer documentation, installation and assembly procedures, and so on.

Design review checklists are commonly used in design reviews to indicate compliance to requirements. When all items on such a basic design checklist are completed, a formal design review is conducted, where final checks and requirements need to be met. The formal design review utilises product specifications, developed earlier to finalise the design process.

Formal design review

The success of a formal design review is dependent on the depth of planning, organisation, and data preparation prior to the review itself. Co-ordination is required regarding the following aspects:

1. Items to be reviewed
2. A selected date for the review
3. The location or facility where the review is to be held
4. An agenda for the review (including definitions of basic objectives)
5. A design review board representing the organisational elements and disciplines affected by the review. Basic design functions, reliability, maintainability, human factors, quality control, manufacturing, and logistics support representations may be included. Depending on the review, consumer and/or individual equipment suppliers may be included.
6. Equipment requirements for the review. Engineering prototypes and/or mock-ups may be required
7. Design data requirements for the review. This may include specification lists, drawings, predictions and analysis, logistic data and special reports
8. Funding requirements
9. Reporting requirements and mechanisms for accomplishing the next follow-up actions, stemming from design review recommendations

The design review has the potential of becoming an all consuming review, and should therefore be tightly controlled. Deviation should be kept to a minimum, and objectives reached expeditiously. The design review has the responsibility to identify and monitor corrective actions, as well as scheduling follow up action for future reviews.

B.4 System Test and Evaluation¹⁵

Systems, no matter how well designed, need to be examined and judged. Elements such as quality of performance, degree of effectiveness, condition and a measure of worth, should be evaluated. The purpose of testing is to determine the true characteristics of the system and ensure that they fulfil their intended requirements.

Different testing procedures exist and this section will shortly define some of the most relevant areas.

Categories of test and evaluation

The specific needs for test and evaluation are initially defined during the conceptual design, when requirements for the overall system are established. Methods must be established for evaluation, to ensure the relevant system meets the initially defined needs. The test procedures are often an ongoing process, consisting of four different types of tests.

Type 1 testing

During the early phases of detail design, this form of continuous testing is often employed to validate solutions to problems, as well as certain performance and physical design criteria.

These tests are not formal demonstrations, but serve to validate design decisions made by the engineer. It is often at this early stage where test results may be directly incorporated into the design, on a minimum-cost basis.

Type 2 testing

Formal tests are necessary to justify and accomplish the latter part of the detail design phase. Prototypes and pre-production units are mostly used. Test procedures may include a variety of tailored processes such as.

Performance tests — specific characteristics of the system is tested and verified with design criteria.

Environmental tests — all systems are exposed to the elements of nature, and these tests make sure the systems are able to function effectively under the necessary requirements.

Structural tests — structural soundness is an important aspect of design and tests such as strain, fatigue, torsion and bending may be used to ensure system integrity.

Reliability qualification — mean time between failure (MTBF) may be of importance in high-risk environments, and need to be checked before a system enters final production.

Maintainability demonstration — although maintainability is often regarded as a military requirement, many other systems are maintained by users. Easy maintenance is therefore essential, as well as testing the time it takes to maintain a system.

Support equipment compatibility tests — tests to make sure the support systems can and will function together.

Personnel test and evaluation — interaction between humans and machinery may be of importance, and if so, tests to verify this are required.

Technical data verification — verification of operational and maintenance procedures are accomplished

Software verification — making sure the operational and maintenance software meet the necessary requirements.

These test procedures serve to qualify the system or product for production and are concluded before the first run.

Type 3 testing

Field tests are often required by the client, especially if a complex system is being manufactured or sold. This is often the first time when all systems and logistic support are operational together. In essence total system performance and operational readiness may be determined.

Type 4 testing

To improve new product design and find possible places for improvement, formal tests are sometimes conducted after the product is already in operation. The test usually takes place at the site of operation, and measures total system performance.

Corrective action — may be necessary in response to system/equipment deficiency, or to improve system performance, effectiveness, and or logistic support. If corrective action is to be accomplished, the necessary planning and implementation steps are prerequisites to ensure complete compatibility of all elements of the system throughout the change process.

Test performance and reporting — are there to identify and report failures and non-compliance to design requirements. Data storage for historic and operational analysis forms an important part of this process. When a test failure occurs, changes have to be made to the system, and these need to be documented. By following a strict data sub-system with criteria for success and failure, the test process is accurately and consistently documented for future reference.

This concludes the discussion on systems engineering and the realisation of innovation.