Reference:
Nigel Cross,
Engineering Design Methods,
Strategies for Product Design,
John Wiley, 1994

5 Establishing Functions

We have seen from the objectives tree method that design problems can have many different levels of generality or detail. Obviously, the level at which the problem is defined for or by the designer is crucial. There is a big difference between being asked to 'design a telephone handset' and to 'design a telecommunication system'.

It is always possible to move up or down the levels of generality in a design problem. The classic case is that of the problem 'to design a doorknob'. The designer can move up several levels to that of designing the door or even to designing 'a means of ingress and egress' and find solutions which need no doorknob at all—but this is of no use to a client who manufactures doorknobs! Alternatively, the designer can move down several levels, investigating the ergonomics of handles or the kinematics of latch mechanisms—perhaps again producing non-doorknob solutions which are functional improvements but which are not what the client wanted.

However, there are often occasions when it is appropriate to question the level at which a design problem is posed. A client may be focusing too narrowly on a certain level of problem definition, when a resolution at another level might be better, and reconsidering the level of problem definition is often a stimulus to the designer to propose more radical or innovative types of solutions.

So it is useful to have a means of considering the problem level at which a designer or design team is to work. It is also very useful if this can be done in a way that considers, not the potential type of solution, but the essential functions that a solution type will be required to satisfy. This leaves the designer free to develop alternative solution proposals that satisfy the functional requirements.

The *function analysis* method offers such a means of considering essential functions and the level at which the problem is to be addressed. The essential functions are those that the device, product or system to be designed must satisfy, no matter what physical components might be used. The problem level is decided by establishing a 'boundary' around a coherent sub-set of functions.

The Function Analysis Method

Procedure

Express the overall function for the design in terms of the conversion of inputs into outputs

The starting point for this method is to concentrate on what has to be achieved by a new design, and not on how it is to be achieved. The simplest and most basic way of expressing this is to represent the product or device to be designed as simply a 'black box' which converts certain 'inputs' into desired 'outputs'. The 'black box' contains all the functions which are necessary for converting the inputs into the outputs (Figure 28).

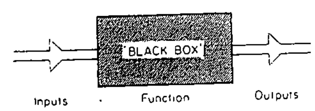


Figure 28
The 'black box' systems model

It is preferable to try to make this overall function as broad as possible at first—it can be narrowed down later if necessary. It would be wrong to start with an unnecessarily limited overall function which restricts the range of possible solutions. The designer can make a distinct contribution to this stage of the design process by asking the clients or users for definitions of the fundamental purpose of the product or device, and asking about the required inputs and outputs—from where do the inputs come?, what are the outputs for?, what is the next stage of conversion?, etc.

This kind of questioning is known as 'widening the system boundary'. The 'system boundary' is the conceptual boundary that is used to define the function of the product or device. Often, this boundary is defined too narrowly, with the result that only minor design changes can be made, rather than a radical rethinking.

It is important to try to ensure that all the relevant inputs and outputs are listed. They can all usually be classified as flows of either materials, energy or information, and these same classifications can be used to check if any input or output type has been omitted.

Break down the overall function into a set of essential sub-functions

Usually, the conversion of the set of inputs into the set of outputs is a complex task inside the 'black box', which has to be broken down into sub-tasks or sub-functions. There is no really objective, systematic way of doing this; the analysis into sub-functions may depend on factors such as the kinds of components available for specific tasks, the necessary or preferred allocations of functions to machines or to human operators, the designer's experience, and so on.

In specifying sub-functions it is helpful to ensure that they are all expressed in the same way. Each one should be a statement of a verb plus a noun—for example, 'amplify signal', 'count items', 'separate waste', 'reduce volume'.

Each sub-function has its own input(s) and output(s), and compatibility between these should be checked. There may be 'auxiliary sub-functions' that have to be added but which do not contribute directly to the overall function, such as 'remove waste'.

Draw a block diagram showing the interactions between sub-functions

A block diagram consists of all the sub-functions separately identified by enclosing them in boxes and linked together by their inputs and outputs so as to satisfy the overall function of the product or device that is being designed. In other words, the original 'black box' of the overall function is redrawn as a 'transparent box' in which the necessary sub-functions and their links can be seen (Figure 29).

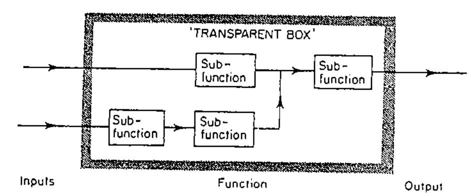


Figure 29
A 'transparent box' model

In drawing this diagram you are deciding how the internal inputs and outputs of the sub-functions are linked together so as to make a feasible, working system. You may find that you have to juggle inputs and outputs, and perhaps redefine some sub-functions so that everything is connected together. It is useful to use different conventions, i.e. different types of lines, to show the different types of inputs and outputs, i.e. flows of materials, energy or information.

Draw the system boundary

In drawing the block diagram you will also need to make decisions about the precise extent and location of the system boundary. For example, there can be no 'loose' inputs or outputs in the diagram except those that come from or go outside the system boundary.

It may be that the boundary now has to be narrowed again, after its earlier broadening during consideration of inputs, outputs and overall function. The boundary has to be drawn around a sub-set of the functions that have been identified, in order to define a feasible product. It is also probable that this drawing of the system boundary is not something in which the designer has complete freedom—as likely as not, it will be a matter of management policy or client requirements. Usually, many different system boundaries can be drawn, defining different products or solution types.

Search for appropriate components for performing the sub-functions and their interactions

If the sub-functions have been defined adequately and at an appropriate level, then it should be possible to identify a suitable component for each sub-function. This identification of components will depend on the nature of the product or device, or more general system, that is being designed. For instance, a 'component' might be defined as a person who performs a certain task, a mechanical component, or an electronic device. One of the interesting design possibilities opened up by electronic devices such as micro-processors is that these can often now be substituted for components that were previously mechanical devices or perhaps could only be done by human operators. The Function Analysis method is a useful aid in these circumstances because it focuses on functions, and leaves the physical means of achieving those functions to this later stage of the design process.

Summary

Aim

To establish the functions required, and the system boundary, of a new design.

Procedure

1. Express the overall function for the design in terms of the conversion of inputs into outputs.
The overall, 'black box' function should be broad—widening the system boundary.

2. Break down the overall function into a set of essential sub-functions.
The sub-functions comprise all the tasks that have to be performed inside the 'black box'.

3. Draw a block diagram showing the interactions between sub-functions.
The 'black box' is made 'transparent', so that the sub-functions and their interconnections are clarified.

4. Draw the system boundary.
The system boundary defines the functional limits for the product or device to be designed.

5. Search for appropriate components for performing the sub-functions and their interactions.
Many alternative components may be capable of performing the identified functions.

Examples

Example 1: A feed delivery system

The function analysis method is particularly relevant in the design of flow-process systems, such as that shown diagrammatically in Figure 30. This represents a factory where animal feedstuffs are bagged.

In this example, the company wanted to try to reduce the relatively high costs of handling and storing the feedstuffs. A designer might tackle this task by searching for very direct ways in which each part of the existing process might be made more cost-effective. However, a broader formulation of the problem—the overall function—was represented in the following stages:

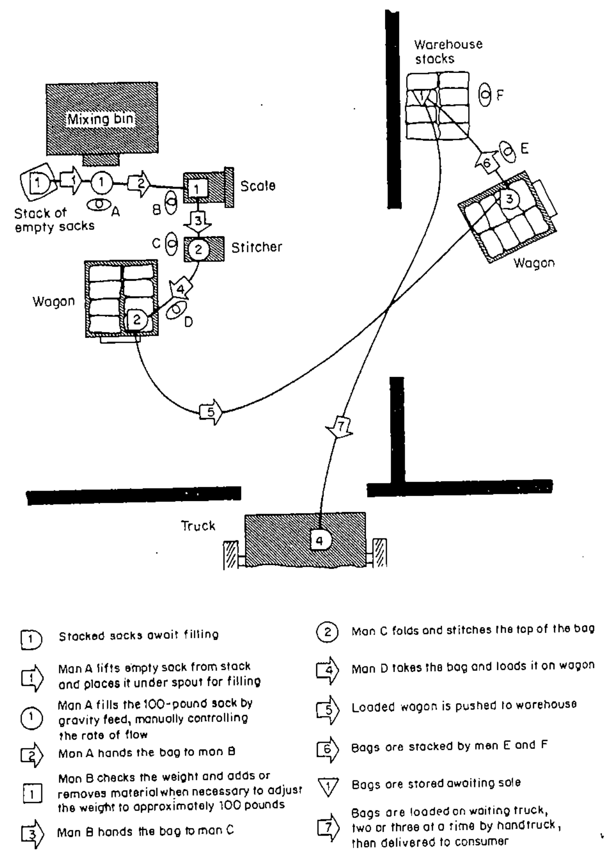


Figure 30 The existing method of filling, storing and dispatching bags of animal feed

1. Transfer of feed from mixing bin to bags stored in warehouse.
2. Transfer of feed from mixing bin to bags loaded on truck.
3. Transfer of feed from mixing bin to consumers' storage bins.
4. Transfer of feed ingredients from source to consumers' storage bins.

This broadening of the problem formulation is shown diagrammatically in Figure 31.

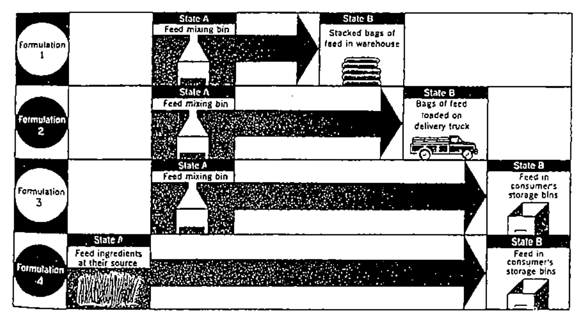
Each different formulation suggests different kinds of solutions, with the broadest formulation perhaps leading to the complete elimination of the handling, storing and loading subfunctions. (Source: Krick.)

Example 2: Packing carpet squares

This example shows another flow process—the packing of loose carpet squares into lots. The designers first broke down the overall function into a series of principal sub-functions (Figure 32).

Some auxiliary functions then became clear. For example, the input from the separate stamping machine includes off-cuts which have to be removed; reject squares must also be removed; materials must be brought in for packaging. The sub-function 'count squares' could also be used to give the signal for packaging lots of a specified number (see Figure 33). (Source: Pahl and Beitz.)

Figure 31
Alternative formulations of the feed distribution problem



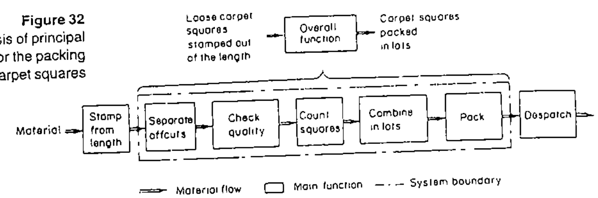


Figure 32 Analysis of principal functions for the packing of carpet squares

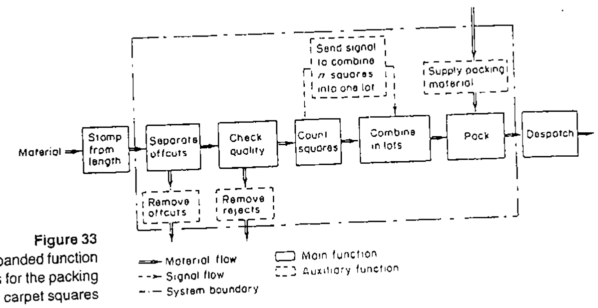


Figure 33 Expanded function analysis for the packing of carpet squares

Example 3: Automatic teamaker

This example is a further development of the project for the design of an automatic teamaking machine, started in the objectives tree method (Figure 24). The fundamental process to be achieved by such a machine is to convert cold water and tea leaves into hot tea (there will also be a need to remove waste tea leaves after the brewing process). This overall function is shown in 'black box' form in Figure 34.

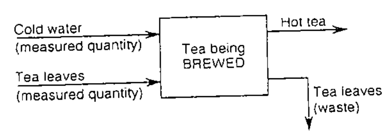


Figure 34 Black box model of the tea brewing process

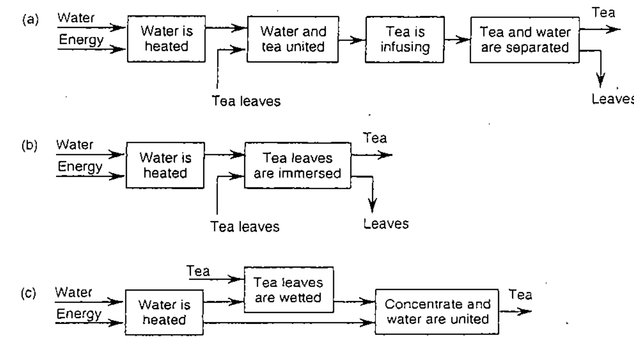


Figure 35 Three alternative process models for tea brewing

Figure 36 Function analysis for the automatic teamaker

After considering various alternative processes by which the overall function can be achieved, the designer settled on the process shown as a flow diagram of sub-functions in Figure 35(a). Various necessary auxiliary functions then became apparent, particularly to do with controlling the heating and brewing processes. The resulting function analysis diagram is shown in Figure 36. (Source: Hubka *et al.*)