4th WDK Workshop on Product Structuring
October 22-23, 1998
Delft University of Technology
Delft, The Netherlands

Conceptual Design of Products and Product Families

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Conceptual Design, Technical System, Synthesis, Product Variety

Abstract

The early phases during design are probably the most important ones. Concept development consists of at least three activities: the establishment of a design specification, functional decomposition and establishment of concepts. The establishment of a design specification is not treated in the paper.
Hubka's procedure has been used successfully at Linköping University for some years, however not exactly as proposed by Hubka. An enhanced procedure for conceptual design is presented in the paper. The procedure is based on Hubka's General Procedural Model, complemented with theories and methods from Andreasen, Hansen & Svendsen, Roozenburg & Eekels, etc.
How should we treat variance between the members of a product family when using the procedure? For some families, the process structure will vary depending on the family member we are focusing on. The function/means tree is a powerful tool for structuring the family. The variance can be created by letting the family members be composed of different functions, or by varying the means for realising functions. The final step is to compose into concepts based on selected means. This is not easy when designing a product; it is certainly not easier when designing a product family.

1. Introduction

It must be stated that the conceptual design phase is probably the most important one and that it will be the base for the whole project. It is certainly not easy to establish good concepts. This requires both experience and skilfulness. By following a procedure, one is forced to thoroughly perform the phases and a procedure gives good support especially for inexperienced designers. In Figure 1 a general description of the design phases is presented and it is shown where the focus of the paper will be.

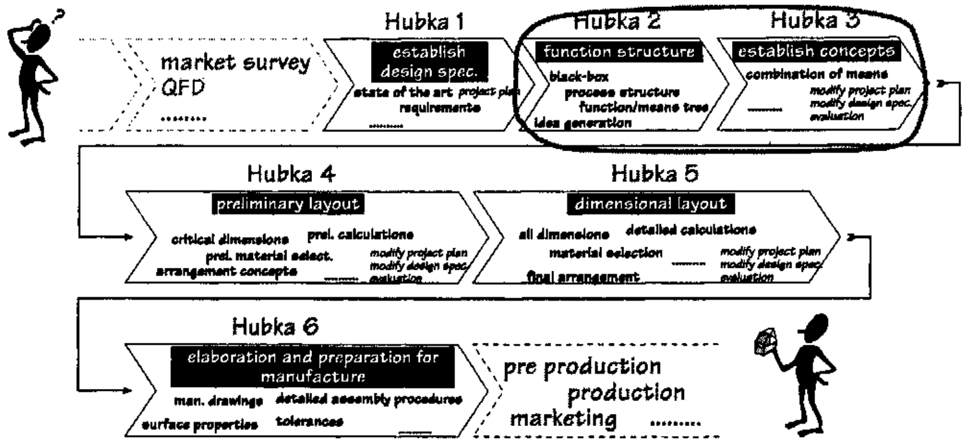

Figure 1. A General Design Procedure, partly after Hubka [10].

There are of course activities in e.g. marketing and manufacturing that are progressing in parallel with the activities shown in Figure 1.

We will not discuss the activity to clarify the customer needs and how to set up a design specification. Our focus will be on how to perform functional decomposition and how to establish concepts. A procedure for conceptual design of products is presented in chapter 3, and in chapter 4 it will be discussed how one could design product families based on this procedure.

2. Theory base

In this chapter, we will shortly present the theory base of the paper. The focus will be on WDK (Workshop Design-Konstruktion) school of design, represented by Hubka's Theory of Technical Systems and Andreasen's Domain Theory. Developing product families means that there should be variety between the family members. Design for variety will be shortly discussed at the end of the chapter.

2.1. The WDK-approach

According to Hubka [11] a technical system is an artefact and creates together with other technical systems, active environment and humans, those effects that are necessary to transform an operand. An operand consists of material, energy, and/or information. A transformation changes the operands internal structure, external structure, or location (also change of time is included, e.g. storing). The functions describe the tasks these systems should do to transform the operand. The functions are realised by organs. An organ is in this paper defined as an abstract representation of relations between parts or functional surfaces, which describes functionality without consideration of material and physical embodiment. The organs are realised by components.

A product can, according to the WDK-school, be described by four structures: the process-, function-, organ- and component structure. Andreasen calls these views of the product for domains. Each of these structures varies from being abstract and undetailed to be more concrete and detailed, as shown in Figure 2.

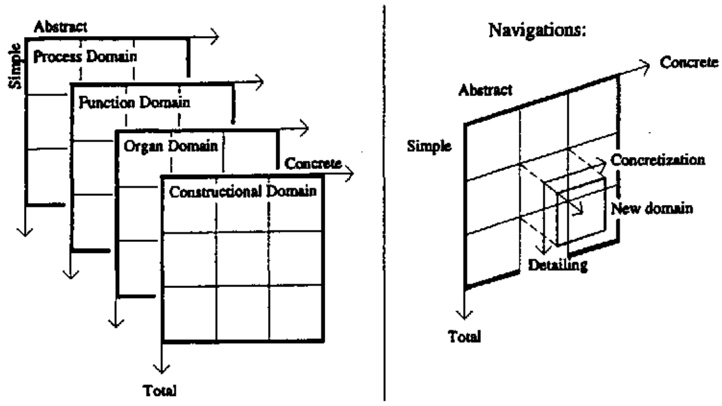

Figure 2. The domains vary from being abstract to be concrete, and from being undetailed to be detailed, from Andreasen [1](redesigned by Malmqvist [14]).

Andreasen [1] points out that design is not as simple as first establishing one domain, then establish the other and so on. During design, one move between the domains in a not so structured way.

The function/means tree

Andreasen states a rule for decomposition:

> *A function can only be decomposed if a means which realises the function has been selected. And: A means is decomposed in accordance with the functions which the means give rise to.*

Andreasen has presented an alternative or simplified way of representing a technical system, that is the function/means tree. A principal function/means tree is shown in Figure 3.

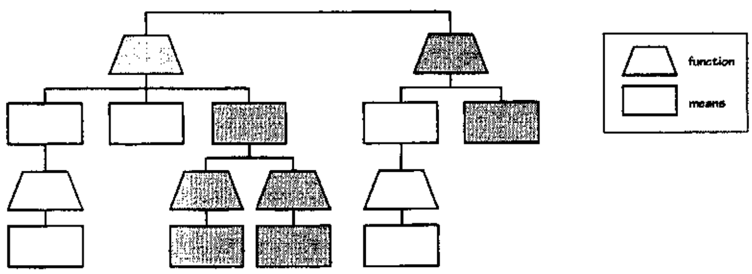

Figure 3 A principal function/means tree showing alternative means, after Andreasen [1].

The selections (grey fields) show one combination of means that could set up, e.g. a concept. The means are of process, organ, and component nature. The means at a higher level are often of a process character and the means at a low level are normally at least a combination of two components (= implementing an organ). For a simple product, the decomposition might end up with only functional surfaces.

Improved function/means tree

The function/means tree can not only be used during decomposition but also when illustrating the composition (configuration) phase. Hansen and Svendsen [7] show an example of this when decomposing and configuring an ultra light aeroplane, see Figure 4.

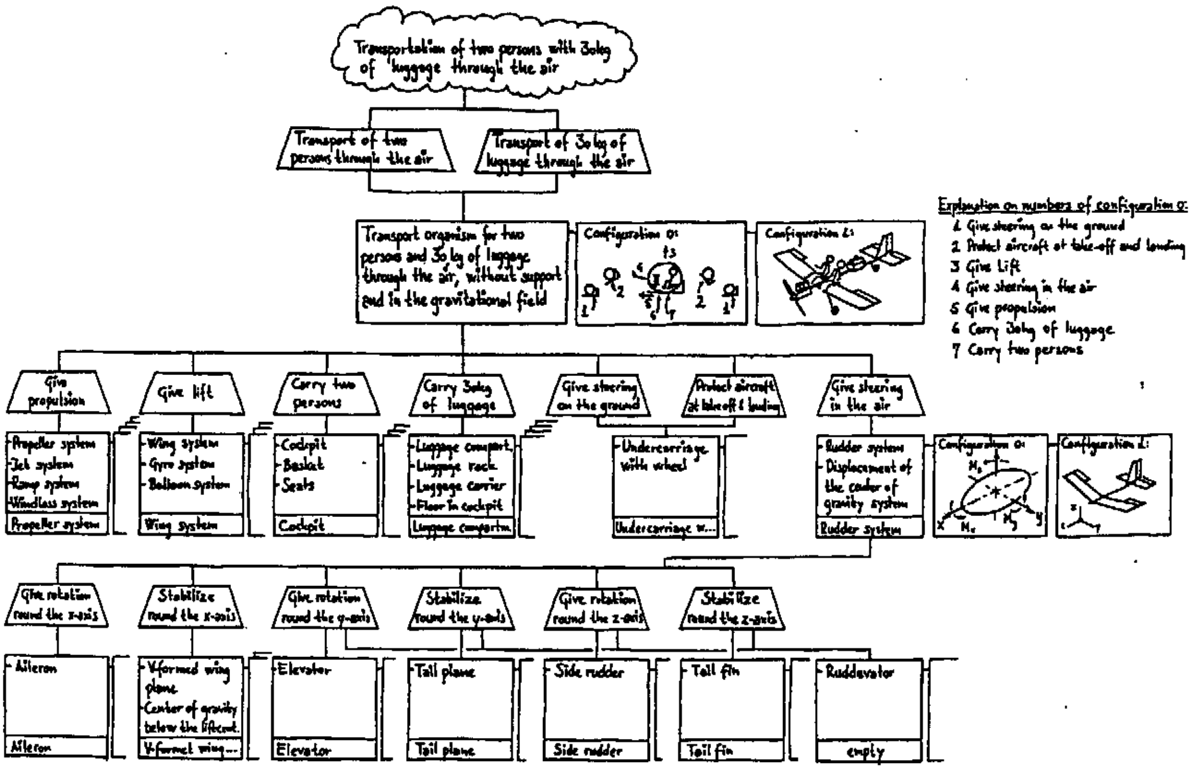

Figure 4. Function/means tree showing decomposition and one configuration of an ultra light aeroplane, from Hansen and Svendsen [7].

The important improvement of the function/means tree is that there for each of the means is a configuration attached. According to Svendsen [19] a configuration includes sub-means, showing their spatial relation and other relations as forces, flows and logical relations between the means. (The term composition is in this paper synonymous with Hansen and Svendsen's configuration).

Hubka's General Procedural Model

In engineering design, there exist several models describing the design process. The most exhaustive ones are probably Hubka's *General Design Procedure* and Pahl & Beitz *Systematic Approach to Engineering Design.* Phase 2 & 3 from Hubka's procedure are used as a base for the procedure presented in this paper. A deeper explanation of the procedure could be found in [10] and a lot of applications could be found in [9]. Hubka's procedure complemented with Andreasen's function/means tree has been used at Linköping University for some years. The procedure has been most successfully used when performing the conceptual design. During preliminary design and dimensional layout (see figure 1) the procedure is too general and not that useful. In the chapter 3, we will present an "improved" version of Hubka's procedure.

2.2. Design for Variety during Conceptual Design

What is a product family? By looking at "related" products on the market one might observe that they might differ according to:

- variation of size
- market variety *(laws, standards, culture, language (e.g. different symbols), ...)*
- variation of performance
- variation of functionality
- aesthetical variations *(colour, shape, surface, ...)*
- etc.

Sometimes the term *product platform* is used in the same context as *product family*. Meyer and Lehnerd [15] define a Product Platform as:

> *".. a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced."*

It seems that the term *product platform* has a wider meaning than *product family*. Products derived from a product platform only have a commonality in the elements that the products are composed of. Product families have similarities in all of its life phases, e.g. in manufacture, distribution, sales, service, use, destruction. We will however not clearly define the terms *product platform* and *product family*.
Meyer and Lehnerd give examples of companies (Motorola, Hewlett Packard, Intel and Microsoft) that have been very successful. One reason might be that:

> *"...they understand that long-term success does not hinge on any single product. They know that they must generate a continuos stream of value-rich products that target growth markets."*

In literature we can find many reasons for creating variety and product families (e.g. [5], [15], [16]). Erixon [5] has developed a method for modularization based on 12 strategic views (the so-called module drivers). Based on an analysis one should then create concepts of modules. His approach requires that one have existing products as a starting point. The result is a redesign of them. Erixon's method can however not be fully applied during conceptual design, e.g. the synthesis part is lacking. The 12 strategic views could however be considered when dividing the product into appropriate subsystems immediately after conceptual design. There is no doubt that Erixon's approach has been most useful for several Swedish companies, and his method is state of the art of modular design.

Establishing a product family means that one aim for different product structures for each family member but with many elements in common. Both Andreasen et. Al. [2] and Hildre [8] have concluded that product variety can be established on process-, function- and organ level.

There is one important difference between redesign of products into product families and novel design of product families. During redesign one tries to identify components and subsystems that could be common for different products. When performing novel design one must state what the differences between the family members should be. This will be further discussed in chapter 4 where we will present different approaches for creating variety during conceptual design.

3. Conceptual Design of Products

In this chapter, we will describe a procedure that is mainly based on Hubka's procedure complemented with Andreasen's function/means tree.

Conceptual design consists of three main phases:

Phase 1. Establish a Design Specification
Phase 2. Functional Decomposition
Phase 3. Establish Concepts (composition)

The establishment of a design specification will not be treated in the paper. The composition phase does not have much similarity with Hubka's original procedure.

3.1. Decomposition

Decomposition is treated in the second phase in Hubka's *General Procedural Model* [10]. In this phase both the process structure and the functional structure are established. The main changes that have been done are the introduction of the function/means tree, a reduction of the number of sub-phases and elucidation and complementary descriptions of the actions in the sub-phases. The description presented here has been tested in education with a good result.

Phase 2: Functional Decomposition

The purpose is to clarify what the product should do, establish the functions of the product and several alternative means/solutions to realise these functions. The base for the functional analysis is the product specification, elaborated in phase 1. The functional decomposition is performed in four steps. These steps are illustrated in Figure 5.

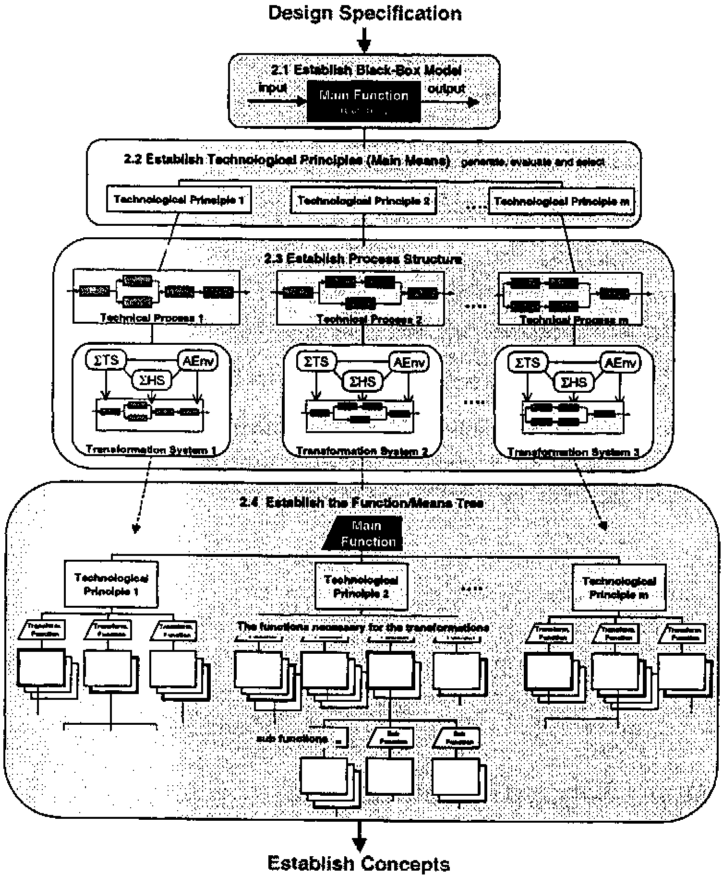

Figure 5. The procedure for functional decomposition.

The functional decomposition begins with investigating the purpose of the product.

Phase 2.1: Establish Black-Box Model

The goal is to establish the main function or purpose, input & output and the operand. The *operand* consists of material, energy, information, and/or biological material. For instance, the operand for a lawn mover is the lawn or the grass. The lawn mover should transform long grass into short grass. The following ***black-box model*** describes the purpose of a lawn mover:

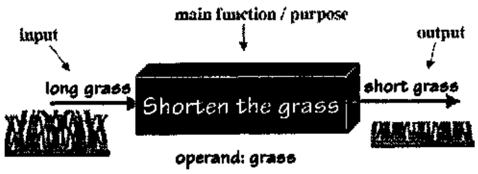

Figure 6. Black-Box model for e.g. a lawn mover.

Often the design task is limited to a subsystem of a product. In order to get a deeper understanding of the problem it is often useful to establish two black-box models with different system boundaries. One model describes the purpose of the design task, and one describes the whole product.

It seems rather easy to establish a black-box model but that is not always the case. There might often more than one possible operand, as the example in Figure 7.

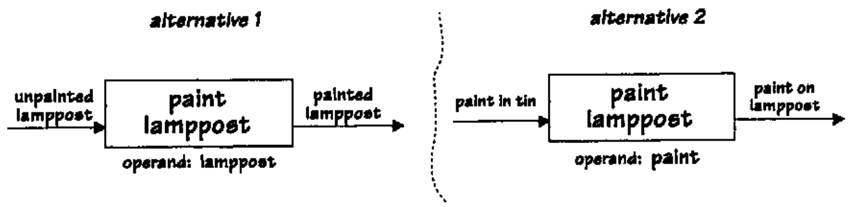

Figure 7. Which operand should one choose?

Sometimes there also exist several operands in parallel for one product. For some types of products (e.g. a table) the output is same as the input.

Phase 2.2: Establish Technological Principles

The *technological principle* describes the technology or principle that the product should be based on. One normally establishes more than one technological principle. They are established in a three-step procedure:

1. Generate technological principles by:
   - using idea generation methods, e.g. brainstorming, analogue methods, TRIZ etc.
   - examine similar products on the market
2. Evaluate the technological principles, consider:
   - if the project is technically realisable if this principle is chosen?
   - if the project is economically realisable if this principle is chosen?
   - obvious advantages and disadvantages
3. Check if the chosen operand is appropriate when choosing this technology:
   - are there any alternative operands?
   - are there more than one operand?

The knowledge of the product is rather limited at this stage which makes it difficult to evaluate technological principles. It is not a matter of selecting the best ones, but to reject those that seem to be technological or economical unrealistic. The technological principles constitute the upper means in the function/means tree (phase 2.4).

Phase 2.3: Establish Process Structure

For every technological principle a process structure should be established. First the transformations the operand should go through are identified. Then it should be decided which systems that should be responsible for these transformations. For systems or subsystems with a more passive manner it might not be that easy or fruitful to establish a process structure.

Phase 2.3.1: Establish Technical Process

The *technical process* shows the transformations of the operand. A transformation changes the operand's (after [10]) internal structure, external structure, position and/or "time" (e.g. by storing).

The process structure is grouped into preparing-, executing-, and finishing phases. An example of a process structure for the feeding system of an upright drilling machine is shown in Figure 8.

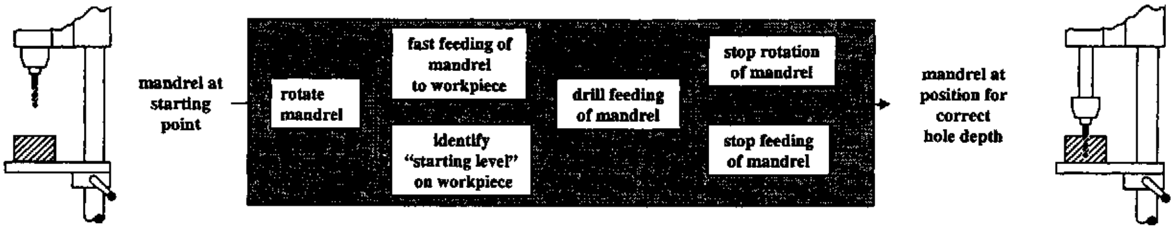

Figure 8. Process structure for the feeding system of an upright drilling machine (partly after Lundberg et. al. [13])

The transformations could be arranged sequential or parallel (or a combination). After the process structure has been established, one ought to examine:

- if there are any alternative transformations
- if the sequence can be changed
- if a transformation should be divided or if transformations should be united

Phase 2.3.2: Establish Transformation System

The transformations are of course not carried out themselves. The systems that could be responsible for the transformations are:

- the technical system (the product that should be developed)
- other technical systems (systems that are designed by others or existing systems)
- the human system (HuS) (when the human act as an operator)
- the active environment

The transformation system for the automatic feeding system of the upright drilling machine is shown in Figure 9.

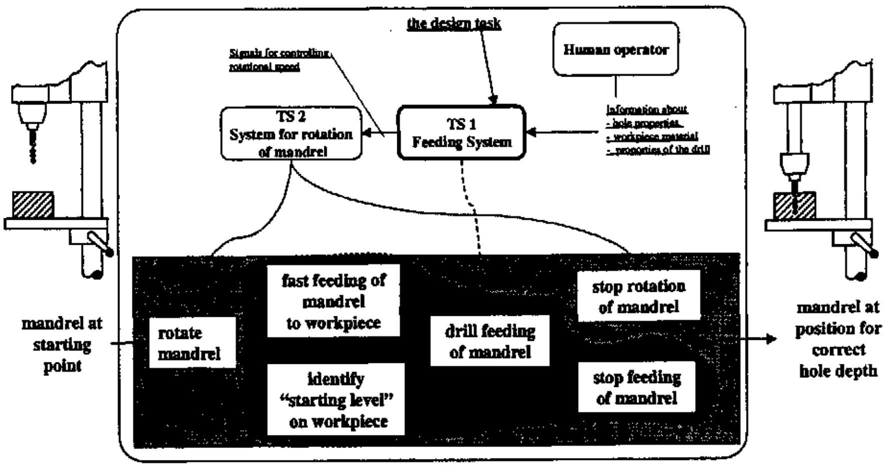

Figure 9. A transformation system for an automatic feeding system of an upright drilling machine (partly after Lundberg et. al. [13]).

The decision of which system that should perform a transformation is of vital important. If we should design a vacuum cleaner and decides that the product itself should be able to locate dust and particles that is far more complicated compared to a normal vacuum cleaner where the operator (human) finds the dust and particles. The decision of what transformations the technical system should do affects the structure of the function/means tree.

Phase 2.4: Establish the Function/Means Tree

The function/means tree is shortly explained in chapter 2. The purpose of this phase is to establish the functions that the technical system should fulfil. One should also establish means for realising these functions. The relations between the function/means tree, the technical process, technical principle, and the black-box model are shown in Figure 10

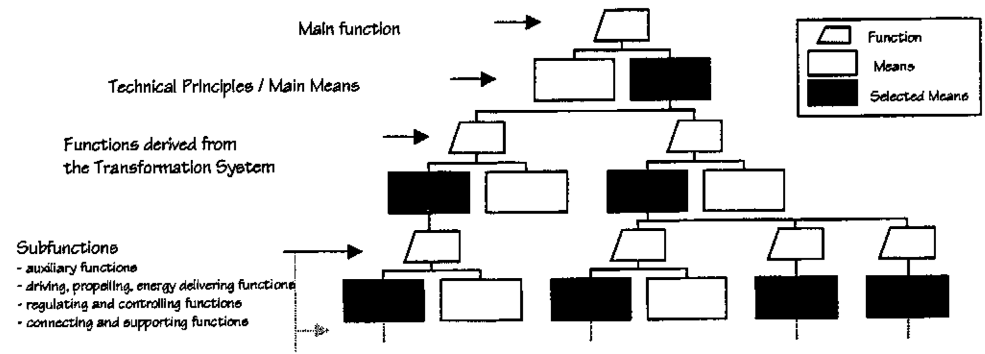

Figure 10. Relations between the function/means tree and the earlier phases during concept development.

The top-level function describes the purpose of the technical system and is the same as the function in the black-box model. The top-level means are the technological principles from phase 2.2. One could sometimes also include the technical processes in the means. The mid-level of functions describes the tasks that the technical system should do in order to (together with humans and other systems) transform the operand(s), as described in the process structure.

Means for realising the functions are found in the same way as when establishing the technological principles, e.g. idea generation. The established means are evaluated so those that have great technological or economical disadvantages are not decomposed further. It must be pointed out that every alternative means results in an alternative branch in the function/means tree. If there are alternative branches it might be wise to split the tree into two trees. It is then easier to make appropriate selections of compatible means on different levels and in different branches. An example of a function/means tree for a fishing reel is shown in Figure 11.

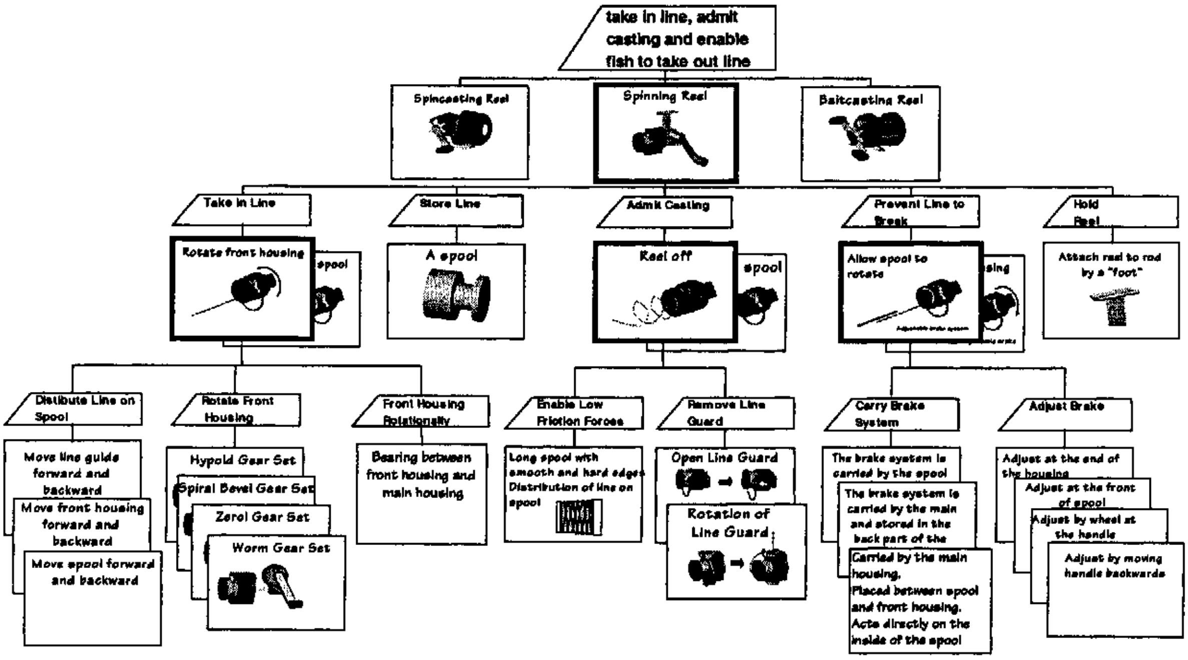

Figure 11. Function/means tree for a spinning reel.

According to Hubka the solutions to functions are organs, but as a designer on normally imagines the solutions as "pictures". The means at the middle level in Figure 11 are illustrated as components. It has turned out to be better to be too concrete when establishing the means in the function/means tree. The means can (ought to) be varied later, e.g. using structure- and form-variation methods from Tjalve [20]. These methods are normally applied after conceptual design and forces the designer to develop different geometrical layouts of the components and the concept. The means at the lowest level in Figure 11 are in this case verbal explanations of the principle; we do not yet have enough information to create geometrical layouts of the means.

3.2. Establishing Concepts (Composition)

In section 3.1 we have described functional decomposition of a problem. The result is a function/means tree, which is the base when composing the means into concepts. Hubka [10] states that establishing concepts from all possible means results in far too many concepts. He also points out that:

> " *...not all solutions are sensible, that not all elements are compatible, can be made together, or will work together. It is therefore recommended that the engineering designer should concentrate on sensible and realistic combinations...* "

Hubka furthermore recommends that solutions that show unimportant variants should be rejected. It is also recommended to establish a concept of as few means as possible, the other means can be added at a later stage. Before explaining the procedure we will first describe how one could limit the total number of solutions and discuss one aspect of examination of compatibility.

Limiting the total number of solutions

When using a function/means tree (or a morphological matrix) the theoretical number of solutions (different combinations of means) will normally be very large. In Figure 12 it can be noticed that the number of possible solutions will be large even for a simple function/means tree.

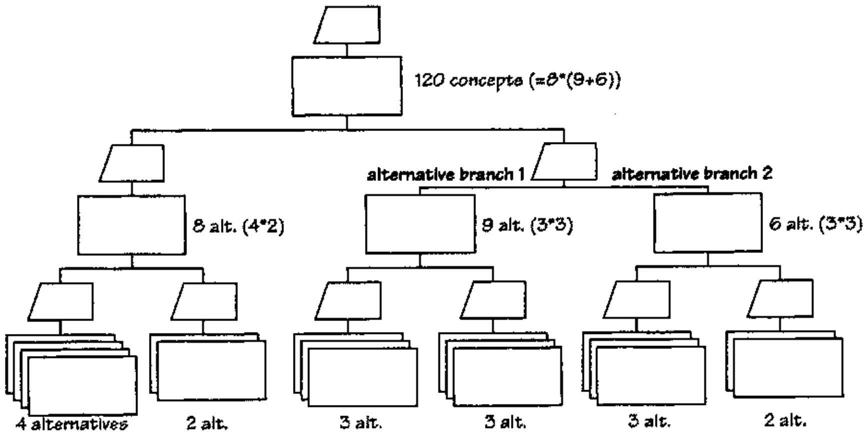

Figure 12. Theoretical number of possibilities to compose concepts from a function/means tree.

It is important to point out that there could be several different arrangements from <u>one</u> selection of means. For Figure 12 it could mean that there would be far more than 120 concepts. It is not possible to establish every possible concept and then evaluate them and select the best ones. We must use a strategy to limit the number of concepts. Roozenburg & Eekels [18] present two methods for reducing the number of solutions.

1 Rank order the solutions to each function by grade of probability of fulfilling the design specification.
2 Arrange the functions (parameters) by degree of importance.

These two methods could of course be combined. The concepts are established by first combining the most promising solutions from the most important functions. Later the solutions to the less important functions can be added.

It must be stated that choosing the best individual solution for each function and combining them into concepts probably does not lead to a good total solution.

Choose compatible means

What is compatible means? Compatibility can be seen from many different viewpoints and components and subsystems must be compatible during every life phase of the product. During conceptual design the means are rather abstract and it might be difficult to judge whether they are compatible or not. One aspect of compatibility might however be investigated. If the means are considered as organs we know that an output from one organ is an input to another. In Figure 13 different types of inputs and outputs are presented.

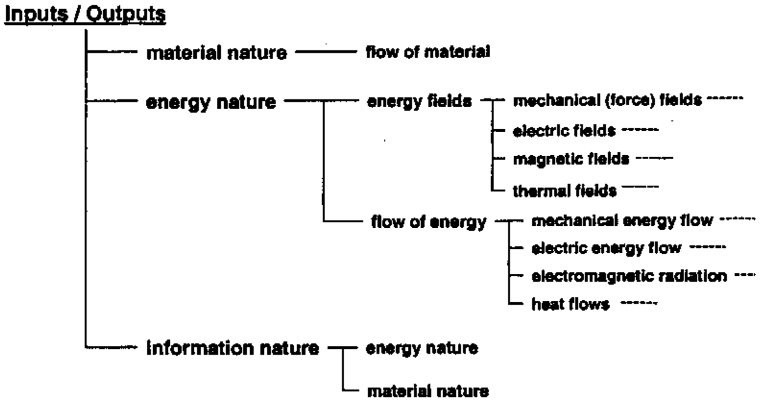

Figure 13. Some input and output types [12].

If we study a propelling system for a vessel one function might be *Store Energy* with the means *Battery, Fuel Tank*, etc., and another function *Convert Energy* with the means *Diesel Engine, Electric motor, etc.* The means *Battery* and *Diesel Engine* are not compatible. The output from the battery could not be the input to the diesel engine. One aspect of incompatibility is that there might be disturbances between the subsystems, e.g. the heat flow from the engine might affect adjacent components in a cars motor compartment. How to deal with this type of incompatibility is discussed by Liedholm [12].

When investigating compatibility during conceptual design one could so then examine:

- the couplings between means, i.e. if the purposeful output from one means is a purposeful input to the other means
- if there are any disturbances between the means.

When we now have gained new knowledge on how to limit the number of solutions and examine one aspect of compatibility, its time to have a look on the procedure. This procedure has however not yet been fully tested and it is not impossible that minor adjustments have to be made.

<u>Phase 3: Establish Concepts</u>

The base for establishing concepts is the function/means tree carried out in phase 2. Phase 3 is carried out in five steps. These steps are illustrated in Figure 14.

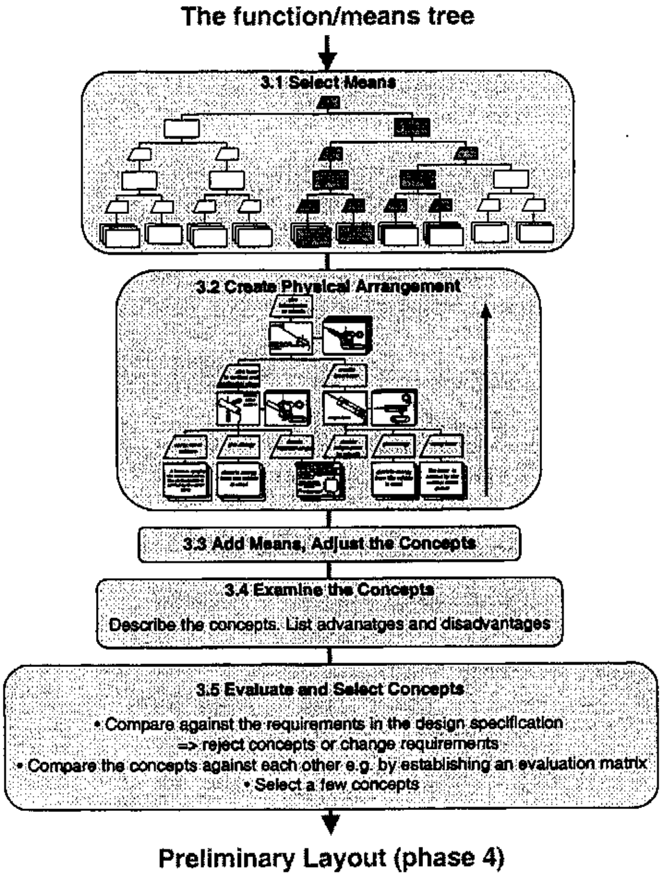

Figure 14. The procedure for establishing concepts.

The establishment of concepts begins with choosing means that the concepts are composed of.

Phase 3.1: Select Means

The starting point is the function/means tree established in phase 2. Means should be selected both at a low and a high level. The selection is a top down procedure; one begins with selecting means at a high level and then downwards the tree to a low level. In order to limit the number of possible solutions Roozenburg & Eekels approach is adopted. The process of selecting means consists of four steps:

1. Rank ordering the alternative solutions to each function by grade of probability of fulfilling the task. The branches under means that are not preferred are not considered any further.
2. Identify the functions by degree of importance. Use a two or three degree scale. Start investigating functions at a high level.
3. Select means for realising the most important functions (means for less important functions will be added to the concept in phase 3.3)
4. Investigate compatibility; adjust the selection of means.

One ought to establish several unique combinations of means. Each selection is represented by a function/means tree with no alternative means (except for the functions that are less important).

Phase 3.2: Create Physical Arrangement of Selected Means

The configuration method presented by Hansen & Svendsen (see section 2.1, and [7], [19]) is used in this phase.

In Figure 15 we have created one arrangement of the spinning reel based on selected means (from the composition phase).

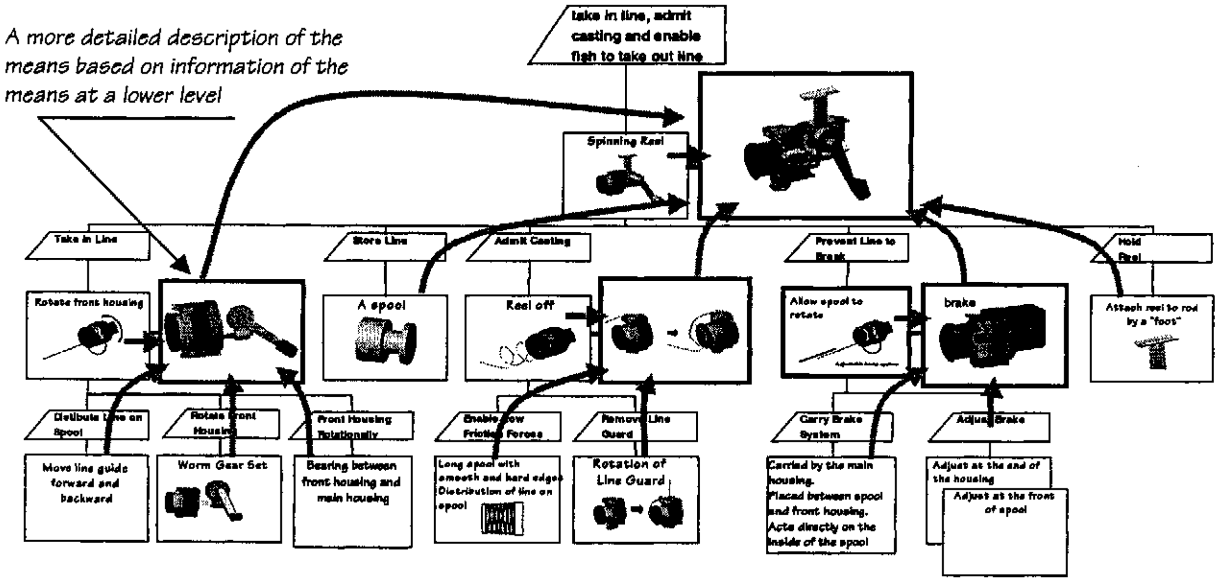

Figure 15. 1st Composition of a spinning reel.

The geometrical layout is created by using information of the means at the lowest level to create a more detailed description of the means at the second lowest level. This new description is used to give a more concrete form of the means at the next level, etc. Finally the top-level means is a detailed description of the concept.

The observant reader may notice that some important functions are missing in Figure 15. When the first composition is established we have more knowledge of the product and can add supplementary functions and generate means for realising these.

Phase 3.3: Add Means, Adjust the Concepts

The concepts should now be adjusted so that the means for the remaining less important functions and new functions are added. One starts by adjusting the means at a low level and gradually changes the means at higher levels. It is of course possible to once again add new functions that we now have found out are necessary based on our new knowledge of the arrangement of the means into concepts, this is however normally only necessary if the new functions seem important. It is time consuming to establish detailed concepts. The concepts should not be more detailed than making it possible to judge if the concept fulfils the purpose of the product and that the concepts can be compared to each other.

Phase 3.4: Examination of concepts

Every generated concept should be thoroughly examined. One should describe how the concept works. This will force the designer to really consider the functionality of the concept. The advantages and disadvantages with the concept must be investigated and listed.

If there are many disadvantages one should examine if it is possible to adjust or replace one or a few means to improve the concept. If the concept is too disadvantageous, it should be liquidated.

Phase 3.5: Evaluate and Select Concepts

The last step in phase three is a final evaluation and comparison of concepts and selection of the most promising ones. It is not easy to make an objective evaluation of the concepts. Hubka [10] states that:

> *"As the statements describing the technical system are still very abstract, the overall evaluation is difficult. The established design characteristics give too little leverage for quantifying most of the requirements that may be selected as evaluation criteria..."*

Though it is difficult one has to make a selection of concepts. The evaluation of concepts is performed in three steps:

1. Compare the concepts against the requirements in the design specification.
   If a concept not fulfils a requirement there are two possibilities:
   - the concept is not good enough
   - the requirement is too "tight"
   Condemn the concept or adjust the requirement.
2. Compare the concepts against each other by establishing an evaluation matrix.
   It is proposed that a rather simple method should be used, e.g. Pugh's Datum Method [17]. At this level, it is difficult to weight the importance of the characteristics and score them for each concept. Roozenburg & Eekels [18] presents many useful evaluation methods which could be used during different phases in design.
3. Select a few concepts to develop further. The selection should be based on the evaluation matrix and the examination of the concepts (phase 3.4).

The numerical result from an evaluation matrix should not be considered as value describing the quality of a concept. It should serve as guidance when deciding which concepts to develop further and which concepts to reject. Fur further development of the concept, one should use the function/means tree as a "map" describing the concept. New functions should probably be added and the means and the compositions should of course be more detailed and concrete. In phase 4 (not described here) one should for each concept e.g. establish preliminary dimensions, establish alternative arrangements (using method described by e.g. Tjalve [20]), select some materials, etc. For complex products, which should be developed by several designers or design teams, it is important to divide the product into appropriate subsystems. The establishment of appropriate sub-systems is influenced by the organ and component structure (via, e.g. the function/means tree) as well as on strategic and company specific reasons.

3.3. Summary

A procedure for conceptual design has been presented. The procedure consists of two main phases:

- Functional Decomposition
- Composition into Concepts.

The output from the functional decomposition is a function/means tree with alternative means and alternative branches. In the composition phase, one begins with choosing the means that the concepts should consist of. Then one should compose these means into conceptual layouts. This is done by adopting Hansen and Svendsen's [7] approach for "configuration", i.e. to use information from the function/means tree. Finally the concepts are evaluated and some of them are selected to be developed further.

4. Conceptual Design of Product Families

Why should we establish *product families*? Erens and Verhulst [4] have motivated the existence of product families by:

> *"Product families are means to improve the commercial variety while limiting the development, manufacture and servicing efforts."*

This chapter will discuss how one should decompose and compose into concepts of product families, and how to create variety during conceptual design.

When designing a product family one has to make decisions what similarities and differences the products should have. The act of setting up a design specification for a product family is a task that is much more difficult than setting up a specification for a single product. Establishing a product family is also a risk; the development costs are much higher than for a single product. On the other hand, one might get successful products with a higher quality and with a distinctive reduction of development and manufacturing costs that can be very lucrative (compared to the development of several single products).

Establishing product families instead of single products requires that one is able to think strategic. One must thoroughly plan the lifetime of the family and plan when the next generation should be designed, manufactured, marketed, and released. This view of designing product families will not be treated in the paper. Instead we will focus on how to create variety during conceptual design.

4.1. Functional Decomposition of Product Families (phase 2)

Both Andreasen et. Al. [2] and Hildre [8] have concluded that product variety can be established on process-, function- and organ level. This will be discussed further in the chapter.

Variance at black-box level (phase 2.1)

The variation between family members could at this level be:

- different types of operands,
- variation in input,
- variation in output, or
- variation of purpose.

Meyer and Lehnerd [15] describe how Black & Decker during the seventies developed a product platform for power tools, e.g. jigsaws, circular saws, drilling machines and sanders. These products' black-box models are totally different regarding operands, input/output states and purposes. The products had their familiarity on, among other things, the component level and on industrial design level. They were easily recognised by the consumer to belong to the same family. They where sharing components as, e.g. motors, casing and gears. The development team also focused on the familiarity for the different life phases.

Microwave ovens are often made as a product family with several variants within the family. The food might be considered as the operand for a microwave oven. If we compare one basic microwave oven with the one with a grill function, we can easily imagine that the output from the black-box model will vary. The output from the basic oven will be boiled food and the output from the other one will be boiled and grilled food.

Variance in technological principle (phase 2.2)
In the Black & Decker case the products had totally different black-box models with different purposes, and they have different technological principles. If a company only develops a product family for hand held drilling machines, they will probably have almost identical black-box models and only minor changes on the technological principle. The changes could occur because some of the drilling machines are also hammer-drills, and some might also be designed as drilling screwdrivers. The effect of totally different technological principles and purposes will perhaps result in several different function/means trees.

Variance at process level (phase 2.3)
At the process level there are two types of variety:
- the family members could have different transformations or,
- there could be a difference in which operators that are responsible for each transformation.

The first case could depend on, e.g. differences in the input or output state of the operands. The second case often results in differences in automation for the products. This could be illustrated by the feeding system of a mandrel for an upright drilling machine. In Figure 16 a technical process for the feeding system of an upright drilling machine is presented. The result of the variance (automatic system or manual system) is that the operators (human and feeding system) responsibilities for the transformations have changed.

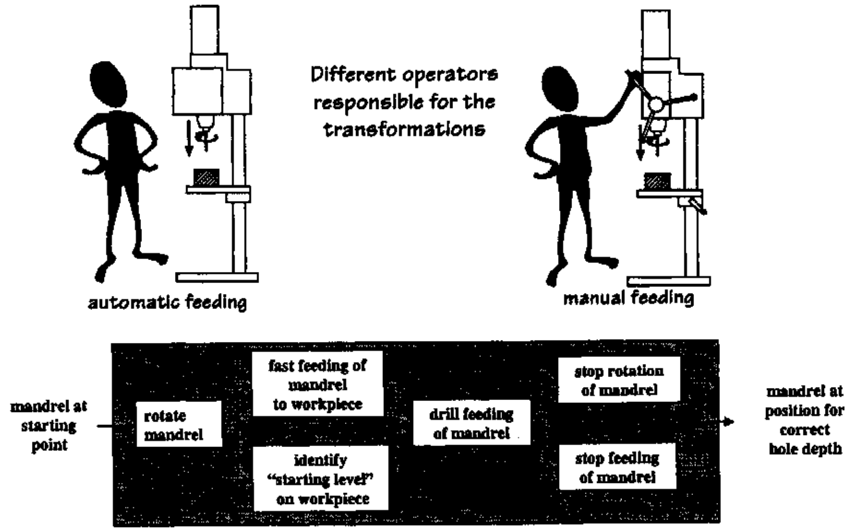

Figure 16. The operators (e.g. the feeding system or the human operator) responsibilities for the transformations will change depending on type of product.

For the manual feeding system the human operator delivers the energy necessary for the movement of the drill chuck, the human also controls the movement of the chuck. A student project [13] has resulted in the development of an automatic feeding system and the building of a prototype. The human operator sets the material date of the work piece and the diameter and length of the hole. Then the upright drilling machine takes the remaining decisions about feeding speed and rotational speed of the drill and finally drills the hole.
Since the prototype was based on an existing upright drilling machine and the interfaces between the original product and the new feeding system was not very complex it might be possible to establish a product family of at least two members.

Variance in the function/means tree (phase 2.4)
Variety could be established by selecting different functions and/or means for different family members. The functions could either be additional or alternative. If the family members have great variety on black-box level, and are based on different technological principles, several function/means tree have to be established. If the concepts of Black & Decker's Power Tools should be designed by using function/means tree, the result would presumably have been several different trees but with many functions and means in common.
Part of a function/means tree for a spinning reel family is shown in Figure 18. It must be observed that only chosen means are illustrated in the figure.

4.2. Establish Concepts of Product Families (Phase 3)

When establishing a concept of a product family, decisions on how the family members composition should be related, must be made. A product family is normally optimised as a family and there is no optimisation of the single-family members without considering the other "relatives".

Composition of product families (phase 3.1 – 3.3)
When designing a product family we have to establish compositions for each family member and this composition depends on how the other family members are composed. As mentioned in chapter 4.1 the family members could be based on some identical functions and some identical means. The variation occurs when choosing:

- additional functions,
- alternative functions,
- alternative means,
- "same" means but different size or performance

This is illustrated in Figure 17.

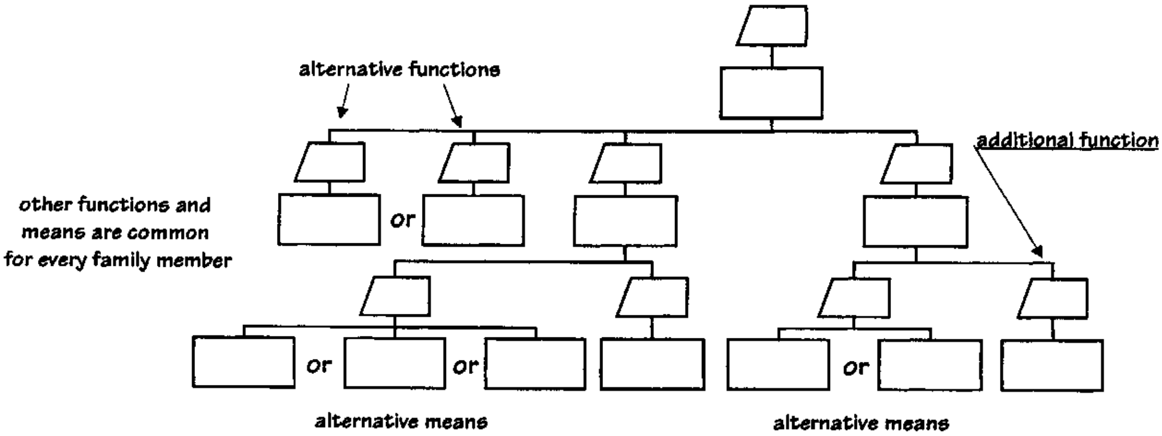

Figure 17. Possibilities for creating variance when using the function/means tree.

An example of composition possibilities for a spinning reel family is illustrated in Figure 18.

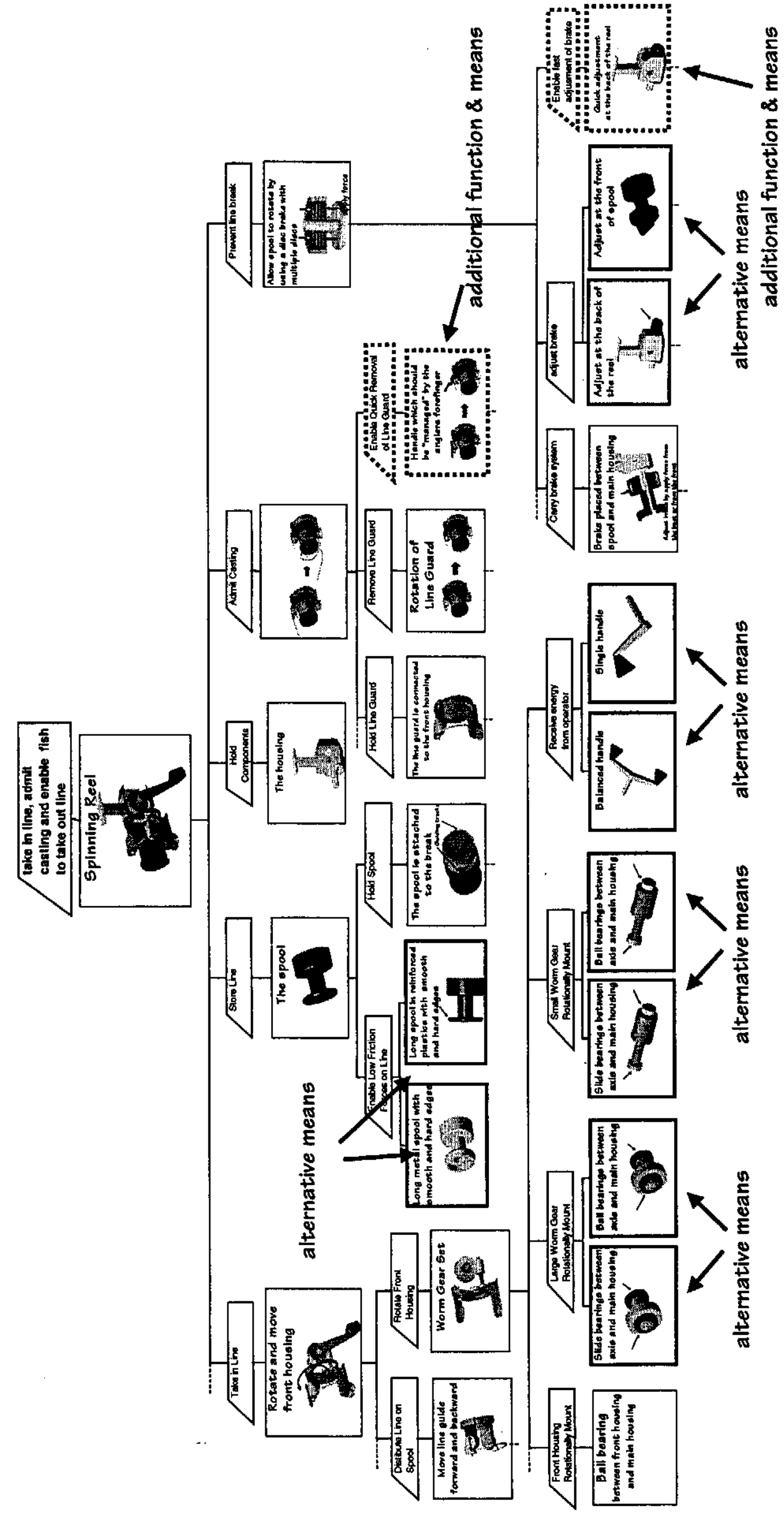

Figure 18. Part of a function/means tree for spinning reel family.

There are at least two different approaches when composing into a product family:

alternative 1. Create a basic composition (concept) based on common functions and means. Adjust the composition by adding means and functions that are characteristic for each family member.

alternative 2. Create a unique composition (concept) for each family member. Then adjust the compositions so the family members are as similar as possible.

The first alternative was used when establishing a concept for the spinning reel family. Possible compositions of the family members are shown in Figure 19.

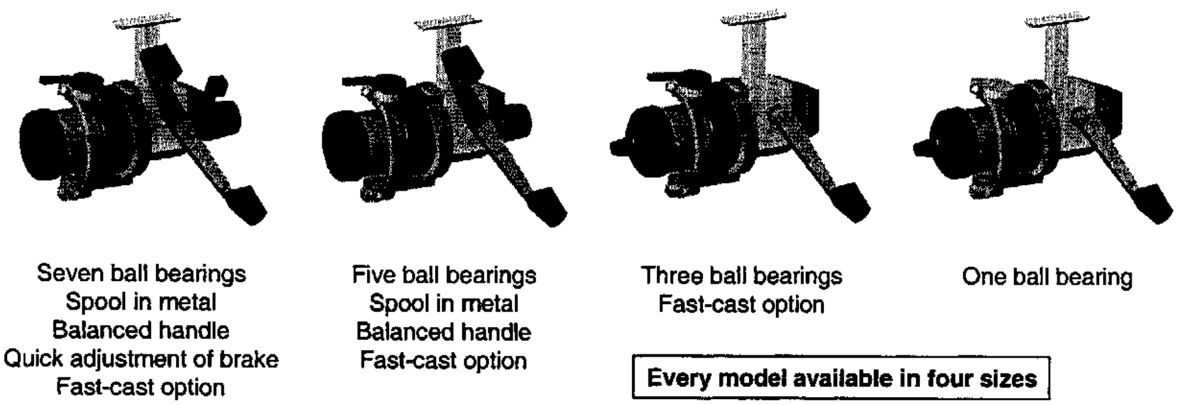

Figure 19. An example of a concept of a product family. The basic composition is established in Figure 15 and complemented with additional and alternative functions and means from the tree in Figure 18.

When establishing a product family as Black & Decker's Power Tool platform the second alternative might be useful.

Examination and evaluation of product families (phase 3.4 & 3.5)

Both the product family as a whole and the individual family members should be examined. When investigating the product family as a whole one should, amongst other things, clearly define which means (subsystems) that should be:

- identical for the family members
- developed in different variants
- specific for the individual family member

It important to investigate if there could be fewer or less complex means or components for the whole product family, without reducing the quality of the individual family members.

The evaluation of product families is much more difficult than evaluation of a single product. More attention should be paid to economic, strategic and production views. Since the concepts might be rather abstract and undetailed this could be a crucial task.

4.3. Summary

In this chapter it has been discussed how one should establish concepts of product families, or rather how to create variance during conceptual design. During conceptual design, variance between the family members could be established on the:

- black-box level
- process level
- functional level (or rather in the function/means tree)

The function/means tree is probably very useful when composing into concepts of product families. The differences between the family members occur because we vary the means, which the products are composed of.

5. Conclusion

The procedure for conceptual design presented in chapter 3 has partly been used in education with a good result. There may be some drawbacks with the procedure e.g.:

- There is not enough support for choosing means in the function/means tree.
- There is a need for support when deciding in what sequence the means or the subsystems should be established directly after conceptual design,
- The function/means tree tends to be rather large. The tree is the key for establishing good concepts but it is not easy to establish, change, and visualise the tree on paper. There is a need for a computer tool to make a function/means tree with many alternative branches manageable. The means in the tree are first rather abstract and undetailed sketches but will later during design consist of detailed cad drawings. The function/means tree could then no longer be established by hand.

It ought to be a challenge in future research to enhance the conceptual design procedure without making it more complicated for the designer. Better tools (e.g. computer tools) for representing the tree is probably one of the keys for successful conceptual design.

The procedure presented here for developing product families is not complete; it must be considered as a *concept of a procedure*, rather than a fully verified and reliable procedure. The focus has been on possibilities to create variety during conceptual design.
The function/means tree is probably very useful when composing product families. In this paper, it has been shown how a concept of a spinning reel family has been established by using a function/means tree. It is however necessary to investigate how other types of product families can be developed. One might have to add some phases during decomposition and composition and perhaps change the existing ones.
Finally, there is a need for guidelines or methods supporting the crucial task to decide what the differences between the family members should be. This is not treated in the paper.

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