Relation Types in Machine Systems

Mogens Myrup Andreasen, Alex Duffy, Niels Henrik Mortensen
Institute for Engineering Design
Building 421, Technical University of Denmark
DK-2800 Lyngby

Summary
A structure is created when a design is synthesized. In the so called WDK school, the design of a machine system follows a pattern of causal related structuring activities which leads to a functionally determined structure.

Many aspects, especially product life aspects, influence the choice of machine system structure. The relations between product structure and the structure of a life phase system or an universal virtue (e.g. cost, time, quality etc.) may be identified as a DFX principle.

This paper illustrates basic synthesis aspects of structuring, it shows examples of the influence of product life aspects. The paper leads to the conclusion that a design may possess several superimposed structural principles to fulfil product life demands.

1. Structuring as synthesis

The WDK-school has chosen to follow a systems or cybernetic approach to the concept of structure. Structure is a characteristic of a system model. A structure is defined as the elements of a system identified by their type, and the relations between these elements.

A finished design or an artefact possesses a structure, created by synthesis. In design solutions (i.e. carriers of functionality), functionality is based on both structure and the element solutions.

The WDK school looks upon design of machine systems as a synthesis from four different viewpoints, namely the machine or design looked upon as

- a system of transformations (Process domain, P6)
- a system of functions (Functions domain, Fu6)
- a system of organs (Organs domain, O6)
- a system of machine parts (Assembly domain, B6)

In the enclosed copies of overheads, domains are explained, the nature of elements and relations are defined, and the structure class belonging to each domain is illustrated.
The domains are causally interrelated, and the design of a machine system may be seen as solving two causal chains:

- a horizontal causality chain following the process pattern related to the machine system, and

- a vertical causality chain establishing the effects necessary, from the organ and assembly structures.

2. Relations in a machine system

It follows from the approach above, that we may "read" more types of relations from a design or an artefact, depending on our viewpoint: process, function, organ or assembly.

When the design is finalised, the assembly structure is that which is directly visible and the carrier of other relation types. (See the overhead illustrations, p.19, 20 and 21.)

3. Structural influences

Experience shows that fitting the product to good performance in all life phases mainly means to adjust or design the structure of the product in accordance with the life phase systems' demands.

An area with well established knowledge, namely assembly and design for assembly as the fitting activity, is chosen. From this area structural rules and principles are shown. Several principles for single product and product family structuring have been identified. (See overhead, p. 24)

4. Structural design, conclusion

The expanded product model, the so called chromosome which has been developed by the Institute for Engineering Design, shows the structure of a design in the four domains (mentioned in section 1) and the relationships between these domains. The characteristics of this model may be grouped into two types of models:

- models for the product's (own) properties, and
- models for relational properties, (e.g. showing how the product's characteristics together with a model of the production system may lead to cost statements).

Structuring a machine system has two principally different features:

- finding a correct configuration (i.e. structuring the design for functionality)
finding a good structure (i.e. optimising more product life aspects (e.g. cost, quality, recycling) related to the product).

This workshop paper has introduced the multi-system approach of WDK and introduced basic concepts of structure and relations. The following statements are central to understand the nature of "designing a structure":

"Other structural principles for specific purposes may be added to a functionally determined structure".

"Several structural principles may be superimposed on a design’s structure".

References


**What does "structure" mean?**

1. Daily life language concept:
   - the way things are built up.

2. WDK school / Systems Engineering / Cybernetics:
   - Structure is a characteristic of a system model.
   - A system model is a model which looks upon an artefact or design as a set of elements and their relations.
   - A structure is the elements identified by their type, and their relations.

![Diagram of artefact, system model, and structure]

**Designing a structure?**

![Diagram of design process]

A: Finding parts solutions → Structure

B: Finding solution → Determining detailed structure

Function = Fu (elementary solutions, structure)
Theory of technical Systems

Process System

Elements: Transformation of Material/Energy/Information

A transformation is a change of properties of an operand:

\[ \text{Operand} \xrightarrow{\text{Transformation or Process}} \text{Operand} \]

Relations:

System Model:

3.

4.
Structuring in the process domain (1):

Task:

Variation:

Solution:

Structuring in the process domain (2):
Function

Function is a category of properties.
Function is the ability of an artefact to create/deliver an effect.

Two types of functions:

Transformation function
   \{ Object (noun) \} is \{ transformed (verb) \}

Purpose function
   to \{ activate (verb) \} \{ effect (noun) \}

Relation:

<table>
<thead>
<tr>
<th>Component</th>
<th>Transformation</th>
<th>Purpose function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor</td>
<td>electric energy is transf. into rotat.</td>
<td>create rotation</td>
</tr>
<tr>
<td>Gear</td>
<td>rot.energy changes revolution/torque</td>
<td>ensure suitable speed of revolution</td>
</tr>
<tr>
<td>Electronic amplifier</td>
<td>signal is amplified</td>
<td>ensure sufficient amplitude</td>
</tr>
<tr>
<td>Battery</td>
<td>energy is stored</td>
<td>provide power</td>
</tr>
<tr>
<td>Diode</td>
<td>AC signal is rectified</td>
<td>reject signals of neg. polarization</td>
</tr>
</tbody>
</table>
The functions of a Telephone:

- **States & Transitions**
  - Idle
  - Sending number
  - Speaking
  - Calling

**Purpose Functional Structure**
- Accept number: input
- Generate electrical signal
- Transmit signals
- Detect calling sound
- Listen to sound
- Receive signals
- Generate electrical signals
- Change state

**Active Purpose Functions**

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**Organ:**

An organ is an artefact, characterized by its functional surfaces and their relations, able to create functions (effects), based on physical laws.

German: Funktionsträger

Examples:

- **Organ for connection**
- **Organ for transformation of movement**
- **Organ for rotation**
System of Organs:

Elements: Organs

Relations: Functional (effects)

System model:

System of Parts:

Elements: Machine parts

A machine part is a one-material, non-decomposable element of an artifact (machine).

Relations: Assembly relations

System model:
Domain relations:

The purpose of a machine is to obtain its output or transformation.

The necessary effects for the transformation are delivered by machine system and man (human operator).

Effects are created by the functionality of the machine.

Functions/effects are realized by organs.

Organs are materialized by machine parts.

Overview:

Fu6:

Ob:

Bo:

Vertical causality chain

Horizontal causality chain

Feed relations:
Logical, causal

Ob relations
Functional (effects)

Bo relations
Assembly
Relation types

In a part structure we may read the O6, Fub and P6.

In an organ structure we may read the Fub and P6.

The nature of a relation:

\[ R(\#A, \#B, \text{art}, \text{value}, \text{derivation}) \]

Characteristics of A and B are related.
Relation types in an assembly structure (B6):

Relation as carrier of

(1) Process relation

(2) Functional relation

(3) Organ relation

A: When lifted
B: Connect to line

When movement transmitted, force shall be taken up
Relation types in an assembly structure (B6) (3)

(4) Part relations (assembly relations)

- Between sub-systems

- Between parts

Examples: Assembly
Examples: Assembly

Structural principles/Assembly:

Single product
Integration
Differentiation
Total Classis
Stacked construction
Compound design
Base component
Building blocks
Standard elements
Modular elements
Re-use elements

Product family
Building blocks
Standard elements
Modular elements
Re-use elements
Preferred numbers design
Building block principle
Parametric design
Group technology

* PRODUCT STRUCTURE FOR FLEXIBILITY

Avoid relations between building elements
Avoid variants in the basic unit
Avoid variants in the building elements
Avoid relations to units with no variants
What is a "good structure?"

Conclusion

To the functional triumvirate structure may be added other structural principles for specific purposes.

Several structural principles may be superimposed on a design's structure.

If you want to make a process oriented structure variation/re-structuring, you have to solve the F1, O, and B relations.