Pugh’s Model: Total Design

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1. Introduction
**Total Design** is the systematic activity necessary, from the identification of the market/user need, to the selling of the successful product to satisfy that need – an activity that encompasses product, process, people and organization [1].

**Engineering Design** is the organized, thoughtful development and testing of characteristics of new objects that have a particular configuration or perform some desired function(s) that meets our aims without violating any specified limitations [2].

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**CAD**: computer-aided design  
**CDS**: component design specification  
**DFA**: design for assembly  
**DFM**: design for manufacture  
**DFP**: design for piece-part producibility  
**E**: external  
**FMEA**: failure mode and effect analysis  
**FTA**: fault tree analysis  
**I**: internal  
**MTBF**: mean time before failure  
**MTTR**: mean time to repair  
**PDP**: product development process  
**PDS**: product design specification  
**QFD**: quality function deployment  
**VOC**: voice of the customer
Total Design generating sales and profits. Whether it is with breakthrough new products, hybrid combinations of older ones, or research into rethinking the entire consumer experience, companies are using total design to generate sales and profits.

The 2004 winners of the Industrial Design Excellence (IDEA) Awards demonstrate that design is playing a critical role for corporations as they turn away from cost-cutting survival tactics to return to strategies of growth.

Examples of winners as follows [3].


2. The Total Design Activity
Typical skills used in new electronic product development [1]

- Industrial design
- Graphic design
- Software
- IT
- Ergonomics
- Electromechanical design
- Mechanical design
- Electronics hardware
- PCB design
- Pack engineering
- Technical writing
- Photography

Product model [1]

Partial design [1]
Design core [1]

- market (user need),
- product design specification,
- conceptual design,
- detailed design,
- manufacture and
- sales

The Design core enveloped by the product design specification (PDS) [1]

- a, b, …, h: Elements of specification,
- Specification formulation
- Conceptual design equates specification,
- Detail design equates to specification,
- Design completely in balance with specification
The Design Core
with Inputs [1]

- Information,
- Mechanical stress,
- Control,
- Electrical stress,
- Mechanisms,
- Costing,
- Hydraulics,
- Manufacture,
- Electronics,
- Information.

Total Design activity model: technology [1]

Total planned
- Materials,
- Mechanical stress,
- Mechanisms,
- Electrical stress,
- Control,
- Manufacture,
- Electronics,
- Information,
- …

The Design Core
with Inputs [1]

- Competition,
- Competition analysis,
- Info acquisition,
- Synthesis,
- Concept selection,
- Data handling,
- Optimisation,
- Cost patterns,
- Market trends,
- Information.

Total Design activity model: technique [1]

Technique organised
- Market analysis,
- a, b,…, h: Elements of specification,
- Specification formulation,
- Synthesis,
- Conceptual design equates to specification,
- a,…, order of importance,
- Decision making,
- Optimisation,
- Data handling,
- Costing,
- …
My experience: unsuccessful example [4 – 6]

Rolling in passes composed by four rolls
← Schematic of the machine
↓ Potential shapes of products-rolled

Underlying reasons of the unsuccessful example

Although the techniques and detail design were successful, but there were problems behind.

A serious deficiency of the market investigation, there were similar metalworking machines (bar mill with 2 roll pass, i.e. shape-rolling).
A omission of the product design specification, there were few elements of PDS, e.g. market constraints, competition, product cost.
A complete lack of a variety of conceptual designs, no comparable concepts to be generated and evaluated.

Diamond synthesis in China


3. Design Core: Market / User Needs
Areas needed to produce the product design specification[1]

Important:
Internet surf
- local,
- national,
- international.

Design activity model showing sources & flow of information [1]
4. Design Core: the Product Design Specification

Elements of the PDS [1]
The PDS (product design specification) is a document that contains all of the facts relating to the product outcome. It defines the elements, factors and boundaries of the artefact to be designed, not the specification of the artefact as designed (the end product itself) [1].

Once the PDS is established, it acts as the mantle or cloak that envelops all the subsequent stages in the design core. The PDS thus acts as the control for the total design activity.

The PDS should try to avoid leading the design and predicting the outcome, but nevertheless it should also contain the realistic constraints to be imposed on the design by either the company or the market.
5. Design Core: Conceptual Design [1]

A **conceptual design** represents the sum of all of the subsystems and of the component parts which go to make up the whole system, or equally a subsystem or the components of the PDS.

The conceptual phase of the design core is primarily concerned with the generation of solutions to meet the PDS.

- Concepts are often best generated by individuals;
- Concept selection and enhancement is often best perform in groups;
- Criteria generation in groups;
- Evaluation of concepts as a group activity.
Apply controlled convergence (CC), Apply concept generation (CG);

Front-end design work -> PDS -> Initial concepts -> CC + CG -> CC + CG -> ...... CC (Concept selected)

Example: 14 Comparable concepts for motor horn
1. Diaphragm + resonator plate + coil;
2. Diaphragm + AS;
3. Electric motor;
4. Diaphragm + Piezo crystal + coil;
5. Signal generator + amplifier + speaker;
6. Motor + fan + reeds;
7. Solenoid + rubber bulb + reed;
8. Continuous tape + amplifier + speaker;
9. Solenoid-operated strip + reed;
10. Solenoid-operated drum stick;
11. Motor + taut wire + auto plucker + toothed disc;
12. Motor + taut wire + rubber-coated disc;
13. Diaphragm + hammers;
14. Speaker + amplifier + microphone + reed.
Concept/criteria against the chosen datum:

+ (plus): better than, less than, less prone to, easier than, etc.;

– (minus): worse than, more expensive than, more difficult to develop than, more complex than, more prone to, harder than, etc.;

S (same): same as datum.

Osborn’s generalized checklist

Put to other uses? New ways to use as is? Other uses if modified?
Adapt? What else is like this? What other ideas does this suggest? Does past offer parallel? What could I copy? Whom could I emulate?
Modify? New twist? Change meaning, colour, motion, odour, taste, form, shape? Other changes?
Streamline? Split up? Understate? Less frequent?
Osborn’s generalized checklist (cont.)


Reverse? Transpose positive and negative? How about opposites? Turn it backwards, upside down, inside out? Reverse roles? Change shoes? Turn tables? Turn other cheek?

Combine? How about a blend, an alloy, an assortment, an ensemble? Combine units? Combine purpose? Combine appeals? Combine ideas?

Example: rating and weighting matrix for brush-making

The basic rating and weighting matrix is organized as in controlled convergence in that concepts are placed horizontally at the top of the matrix with criteria for evaluation on the left-hand side.
Bottle-brush making: linear continuous machine

Bottle-brush making: rotary continuous machine
Bottle-brush making: non-continuous machine, two station

Bottle-brush making: non-continuous machine, four station
Matrix for brush-making machine

Weighting factor: 1 – 5 or 1 – 10 scale.
Rating: 1 – 5 or 1 – 10 scale.

Weighting factor ↑, importance ↑;
Rating ↑, good ↑.

6. Design Core: Detail Design (Technical Design) [1]
Deducing design specification

Deductive skill → product → manufacture → Detail → Concept → specification → user need

Deduce knowledge used: materials, energy sources, control, etc.

Deduce methods used: manufacture, information, physical principles, etc.

Details - overlap is acceptable, omission is not!

Reduction in: the total number of parts, the amount and complexity of machining, material usage, the costs of components and hence overall machine cost, assembly time, the number of drawings.

Improvement in: the overall appearance of the product / machine, the machine reliability.
The complexity factor

$$C_f = \frac{K}{f} \sqrt[3]{N_p N_t N_i}$$

K: Constant of convenience,
f: the number of functions that the product is expected to perform,
Np: the number of parts,
Nt: the number of types of part,
Ni: the number of interconnections and interfaces.

The $C_f \downarrow$, the equipment’s reliability $\uparrow$,
its cost $\downarrow$, its quality $\uparrow$.

Aids to detail design: examples [8,9]

Example 1: Textile Composite Cellular Structures

Example 2: choice of Lubricants for cold metal forming

<table>
<thead>
<tr>
<th></th>
<th>Soap + molykote</th>
<th>Soap</th>
<th>MoS2</th>
<th>Kerestene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
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<tr>
<td>FEM</td>
<td></td>
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</tr>
<tr>
<td>$\tau = \mu P$</td>
<td>$\mu = 0.04$</td>
<td>$\mu = 0.06$</td>
<td>$\mu = 0.12$</td>
<td>$\mu = 0.14$</td>
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<td>$\tau = m$</td>
<td>$\alpha = 0.07$</td>
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<td>$\alpha = 0.26$</td>
<td>$\alpha = 0.32$</td>
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<tr>
<td>$\tau = \text{A}$</td>
<td>$\beta = 0.20$</td>
<td>$\beta = 0.36$</td>
<td>$\beta = 0.52$</td>
<td>$\beta = 0.63$</td>
</tr>
<tr>
<td>$\tau = \text{P}$</td>
<td>$\gamma = 0.10$, $h = 0.76$</td>
<td>$\gamma = 0.277$, $h = 0.76$</td>
<td>$\gamma = 1.387$, $h = 0.57$</td>
<td>$\gamma = 1.634$, $h = 0.57$</td>
</tr>
</tbody>
</table>

Costing equation:

$$C = \frac{R}{60} \left[ \frac{N_d K_c}{3100} + \frac{N_d S_t}{X Q} \right] + M$$

- $R$: the hourly labour rate;
- $N_d$: the component complexity factor;
- $K_c$: the combined factor ($K_1$, $K_2$, $K_{\text{mat}}$);
- $L$: the total machined setting time, min;
- $D_m$: the mean diameter (mm);
- $S_t$: the machine setting time (mins);
- $X$: the machine tooling capacity;
- $Q$: the batch size;
- $M$: the material cost / component;
- $K_1$: the machining factor;
- $K_2$: the machine type factors;
- $K_{\text{mat}}$: the material factor.
7. Design Core: Manufacture

Two key elements:
(1) Design for assembly (DFA);
(2) Design for piece-part producibility (DFP).

Design for
- manual assemble;
- high-speed automatic assembly;
- Robot assembly.

Many different types of production process
for making piece-parts, and information must
be available for each of these many types.
8. Design Core: Selling (marketing)

Consider “Voice of the customer” in great detail.
Taguchi methods

Process A incurs more loss to society than process B.

All efforts are directed at reducing variability and achieving target values.

Total Design: A Summary
<table>
<thead>
<tr>
<th>Design core</th>
<th>Techniques applied</th>
<th>To yield</th>
<th>To benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Market</td>
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<td></td>
<td>Specification</td>
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<tr>
<td></td>
<td>Concept design</td>
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<td>Detail design</td>
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<td>Manufacture</td>
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<td>Sell</td>
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<td></td>
<td>Information and competitive analysis; Parametric analysis; PDS as interrogator</td>
<td>Understanding of competition, their technology and markets</td>
<td>Customer company &amp; employees (CCE)</td>
</tr>
<tr>
<td></td>
<td>QFD ‘voice of the customer’; PDS formation</td>
<td>Customer requirements &amp; constraints</td>
<td>(CCE)</td>
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<tr>
<td></td>
<td>Concept generation / selection matrices; QFD matrices</td>
<td>Invaluable concepts in shorter time frames</td>
<td>(CCE)</td>
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<td></td>
<td>Optimization / parameters; QFD matrices</td>
<td>Better components</td>
<td>(CCE)</td>
</tr>
<tr>
<td></td>
<td>Just-in-time; statistical processcontrol; MRP; QFD matrices</td>
<td>On-line QC; reduced inventory</td>
<td>(CCE)</td>
</tr>
<tr>
<td></td>
<td>PDS – interrogation “voice of customer” – QFD</td>
<td>More profit</td>
<td>Customer satisfaction</td>
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