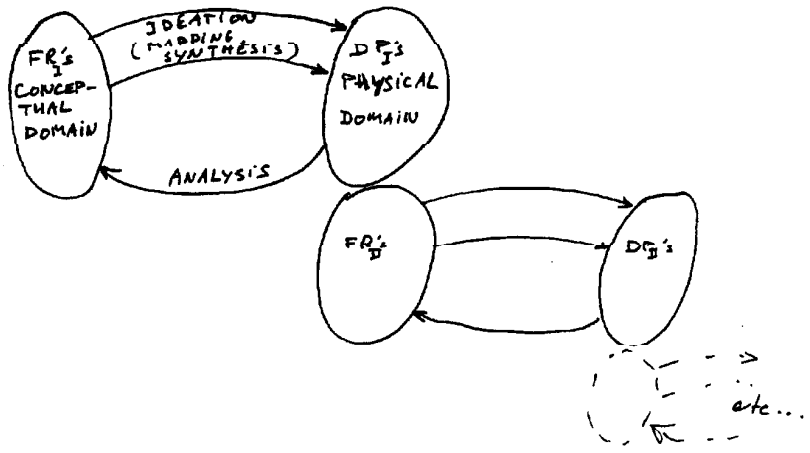
Basics of the Axiomatic Approach to Design[1]

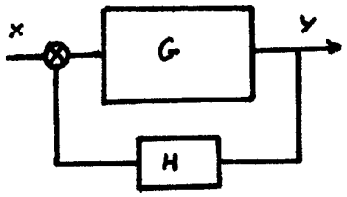
By Jean LeMee

The Functional Space and the Design Parameters Space are linked by the Ideation Process (synthesis or mapping).



By this process, the designer looks for possible solutions or ways of physically satisfying the stated functional requirements.

The loop is closed by the Analytical Process by which the designer analyses the solution to tailor it more and more closely to the stated FR's or to propose a new set of FR's if no solution can satisfy the original FR's within the constraints.



G = Synthesis ability
H = Analytical ability
large GH helps the design process

$$\frac{y}{x}=\frac{G}{1+GH}\cong\frac{1}{H} \quad for\ GH\gg 1$$

(1) Principles of Design, Nam Suh; Oxford University Press, NY 1990

The Design Process consists therefore of a constant cycling back and forth, a feedback loop or iteration, between the Functional Domain and the Design Parameters Domain (Physical Domain).

There is a Hierarchy in both the Conceptual Domain (Functional Space; FR_I's, FR_{II}'s, FR_{III}'s...etc.) and the Physical Domain (Design Parameters Space, DP_I's, DP_{II}'s, DP_{III}'s etc.)

. The first step in design is therefore to define a set of FR's that satisfies the perceived needs.

. The second step is the re-ordering of the elements of creation (natural or artificial) that will satisfy the FR's with the minimum of re-ordering along the whole life cycle of the design.

The specifications by which this re-ordering should be done are the DP's.

FR's are the designer's characterization of the perceived needs for a product

FR's are defined as the minimum set of independent requirements that completely characterize the design objective for a specific need.

If in a set of FR's, some FR's are related to one another (i.e. are not independent) this sub-set of FR's can be reduced to one single independent FR. The sub-set is said to be redundant.

The First Axiom states:

"Maintain the independence of the functional requirements."

Since, by definition, the functional requirements are independent, the axiom states that this independence must be maintained through the design process.

i.e. The design parameters chosen (DP's) should not establish links between the FR's. In other words, the design matrix relating DP's to FR's should be diagonal (uncoupled or at least triangular (decoupled) but should not be complete (coupled).

FR = A DP

$$\begin{bmatrix} x & o & o \\ o & x & o \\ o & o & x \end{bmatrix} ; \begin{bmatrix} x & o & o \\ x & x & o \\ x & x & x \end{bmatrix} ; \begin{bmatrix} x & x & x \\ x & x & x \\ x & x & x \end{bmatrix}$$

uncoupled decoupled coupled

This choice of DP's satisfying FR's must be such that the constraints are not violated.

Constraints are parameters that put a bound on acceptable solutions. They delimit the "Design Space."

They are of Three Kinds:

1. Intrinsic Constraints or constraints on Design Specifications (e.g. weight, size, cost etc.) (also called Input Constraints)

2. Extrinsic Constraints imposed by the system environments in which the solution must function (e.g. Laws of Nature: Physical, Biological; Laws of Society, Social Environment, etc...)(also called System Constraints)

3. Human Constraints, inherent to the designer and the client (view point, stand point).

Example of use of the axiomatic approach: HW. 1-6
Foundation of Government from the view point of Design Axioms

According to William Blackstone, (1723-1780) a noted British Jurist, "The Natural Foundations of Sovereignty" or requisites that ought to be found in every well constituted frame of government are:

. wisdom
. goodness
. strength

Taking these qualities as functional requirements at the highest level for a government, one can establish corresponding DP's:

FR_I A_I DP_I

$$\begin{bmatrix} Wisdom \\ Goodness \\ strength \end{bmatrix} = \begin{bmatrix} x & o & o \\ o & x & o \\ o & o & x \end{bmatrix} \begin{bmatrix} Provide\ for\ Justice \\ Legislate \\ Enforce \end{bmatrix}$$

At The Next Level:

FR_{II} A_{II} DP_{II}

$$\begin{bmatrix} Provide\ for\ Justice \\ Legislate \\ Enforce \end{bmatrix} = \begin{bmatrix} x & o & o \\ o & x & o \\ o & o & x \end{bmatrix} \begin{bmatrix} Courts \\ Congress \\ Elective \end{bmatrix}$$

One could go on, for instance taking Congress:

$$FR's_{III} = \begin{bmatrix} Legislate \\ Advise \\ Consent \end{bmatrix} [under\ constraints\ of] \begin{bmatrix} Elective\ Vetoes \\ Executive\ Choices \end{bmatrix}$$

HW. 2.1

Develop the FR and DP hierarchies for a bicycle:

First Level of FR's might be

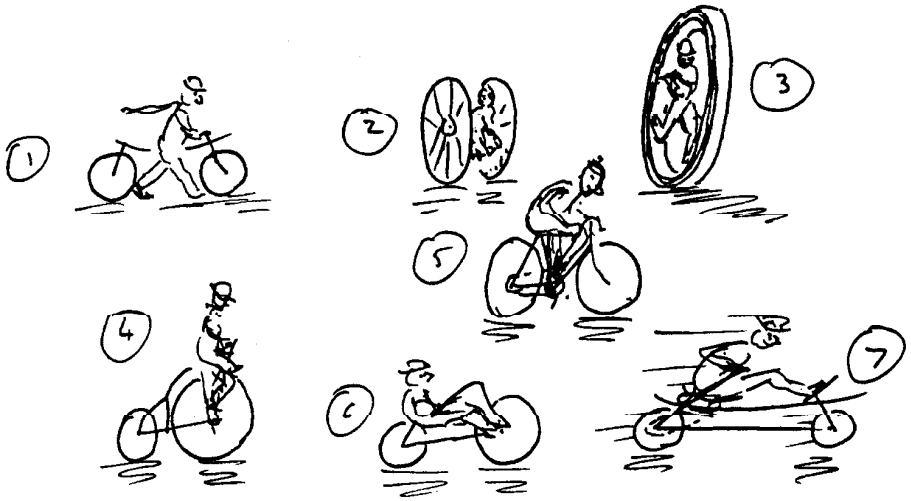
1. Man-powered
2. Stable at reasonably low speeds
3. Ability to change direction
4. Ability to stop
5. Sturdy
6. Light
7. Cost less than $150.00

Actually 6 and 7 may be considered to be constraints by restating 6 as:
Must weigh less than 25lbs.

1 through 5 being our FR's we now try to find various ways of satisfying these requirements in the physical domain.

"Bicycle" means our device should have <u>two wheels</u>.

Here are some possibilities:



The first set of FR's and DP's for say Solution 5 are:

FR_I	DP_I
1. Man-powered	1. pedal/chain/sprocket
2. Stable at reasonably low speed	2. Wheels diameter < 3ft.
3. Ability to change direction	3. Handlebar on front wheel
4. Ability to stop	4. Brakes on both wheels
5. Sturdy	5. Triangular/tubular construction

Constraints

1. Light < 25 lbs1. Material: Aluminum alloys

2. Cost < $150.002. Price range for all items

Now to establish the next level of FR's (FR_{II}) start with each of the DP's in the DP_I list:

FR_{II}:

$(DP_{I1})FR_{II1}$
- Max Torque/Minimum Torque
- Maximum force on chain
- Transmit torque unidirectionally(free wheel)

$(DP_{I2})FR_{II2}$
- Max & min. wheel diameter
- Wheel rigidity, flexibility
- Dynamics of bicycle operation
- Position of Center of Gravity

$(DP_{I3})FR_{II3}$
- Ensure wheel directional change within 45°
- Keep body position comfortable & secure
- Ensure good body effort transmission
- Carries all manual controls (e.g. derailleur)

$(DP_{I4})FR_{II4}$. Front & back brakes to work independently
. Simple
. Reliable
. Stop & vehicle at 20 mph on 20 ft.

$(DP_{I5})FR_{II5}$. Easy to manufacture
. Easy to maintain
. Does not interfere with access of any working part for repair
. Provide sufficient rigidity to the whole assembly
. Resist mechanical shocks
. Indifferent to weather conditions

Constraints

$C._1$ --> . Easy to weld
. Easy to machine
. Easy to maintain
. Total Weight < 25lbs.

$C._2$ --> . costs item/volume

We now proceed to establish DP_{II}'s corresponding to the $FR_{II's}$:

DP_{II1} . 3 speed max; specific design for maximum. & minimum torque required
. choose chain from manufacturers satisfying maximum force
. choose specific design for sprocket
etc...

HW 2-6

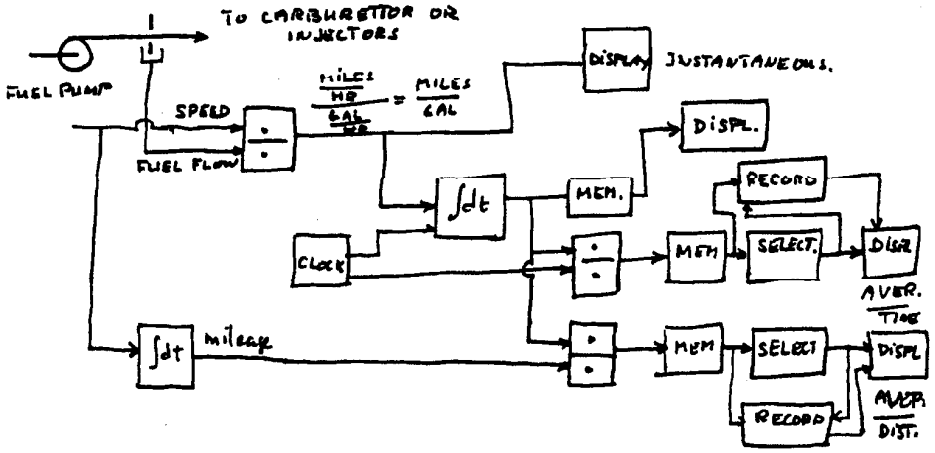
Use of "House of Quality" concept to improve the design of taxi doors used by passengers.

Customer Attributes:	FR's	Priority
. Easy to operate	Easy to open	
	-from inside	(2)
	-from outside	(2)
	Easy to close	
	-from inside	(2)
	-from outside	(2)
. Plenty of Room	. Give ample and easy access to seat	(1)
	. Head room sufficient for person in wheelchair	(3)
	. Leg room sufficient for tall person	(3)
. Safe	. Does not stick out in traffic (signal)	(4)
	. Child proof lock	(5)
	. Does not tend to become more difficult to close when car is running	(2)

HW. 2.7 Mile/Gallon Indicator

FR
1. Instantaneous readings
2. Reading averaged over last x hours of driving
3. Reading averaged over last y miles of driving

Ideation . Possible Solutions:



DP
1. Instantaneous fuel flow and speed measuring devices.
2. On line computing elements for division and integration.
3. On line clock signal.

Constraints:

Space < 5" x 3" x 1"

Weight < 8. oz.

Cost < $50.00