Generating Design Concept

Morphological Chart

- Proposed by Zwicky
- Steps to follow

1. Arrange the functions and subfunctions in logical order
2. List for each subfunction "*how*"
3. Combine concepts

Example "CD case"

Subfunction	Concept				
	1	2	3	4	5
1.0 Open case					
1.1 Hold and grip case	Flat box	Groove box	Curved box	Case with handle	Rubber grip strips
1.2 Disengage lock	Friction lock	Inclined plane lock	Magnetic lock	Clamp lock	Clicking hinge lock
1.3 Expose CD	Conventional hinge	One-piece flex plastic hinge	Slide-out, like match box	Tilt like shampoo bottle top	
2.0 Extract CD					
2.1 Disengage from securing system	Conventional Rosetta	Lift/lock device	Padded cradle		
2.2 Grasp CD and remove	Hand				

Example "CD case"

Subfunction	Concept				
	1	2	3	4	5
3.0 Extract leaflet 3.1 Disengage from securing system 3.2 Remove leaflet	Tabs Hand	Holding slot	Velcro straps	Tab that swivels	No securing system
4.0 Replace CD 4.1 Place CD in securing system 4.2 Engage securing system	Hand 2-finger push	Whole hand			

Example "CD case"

Subfunction	Concept				
	1	2	3	4	5
5.0 Replace leaflet 5.1 Place leaflet in securing system 5.2 Engage securing system	 Slide into position Slide under tabs or in slot	 Lay in position Swivel tabs	 Attach Velcro		
6.0 Close case 6.1 Engage lock	 Friction surfaces	 Put magnet together	 Slide platen into position		
7.0 Store case 7.1 Place case in desired location	 Put on table	 Put on another CD	 Put in special CD holder		

The combinations of these concepts generate many possible solutions for the design.
There are 162,000 combinations in this design.

Assume that 5 concepts are drawn from the previous chart.

Concept 1: Conventional square box (1), with the incline plane lock (2) and a slide-out matchbox (3) for a hinge. The CD is secured with a conventional "rosetta" (1) while the leaflet is secured with tab (1).

Concept 2: A streamline curved box to fit the hand (3), with a friction lock (2) and a conventional hinge (3). The CD is secured in padded elastomer cradle (3) and the CD case are designed to stack flat (2).

Concept 3: The box is grooved to the shape of the finger (2), with a magnetic lock (3) and conventional hinges (1). A new lift/lock secures the CD (2). The leaflet fits in a slot in the top of the case (2).

Concept 4: A standard square box (1) with magnetic lock (3) and conventional hinges (1). The CD is secured with a padded cradle (3), while the leaflet is secured with Velcro straps (3).

Concept 5: A curved box (3) with inclined plane lock (2), with a slide-out matchbox (3). The CD is held by a rosetta (1) and the leaflet fits into a slot (2). The cases are designed to stack (2).

Axiomatic Design

- Developed by Professor Nam Suh and his colleagues at MIT
- Focus around 2 design axioms

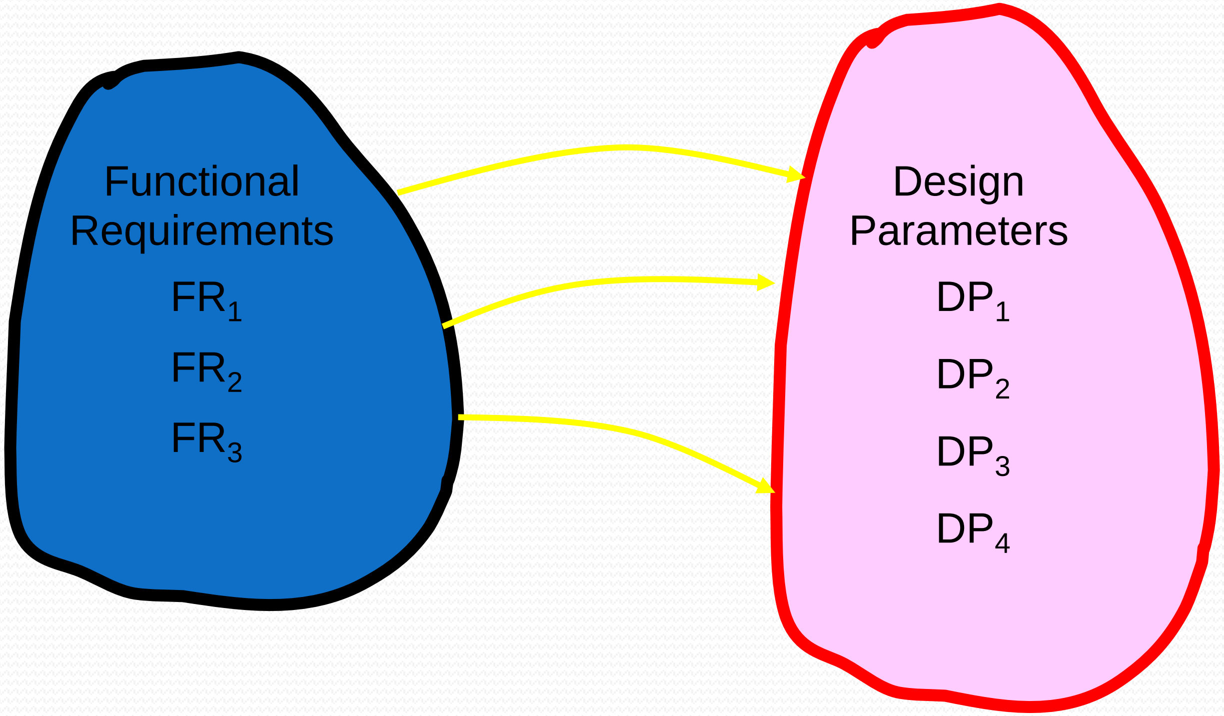
Axiom 1: *The independent axiom*

Maintain the independence of functional requirements (FRs).

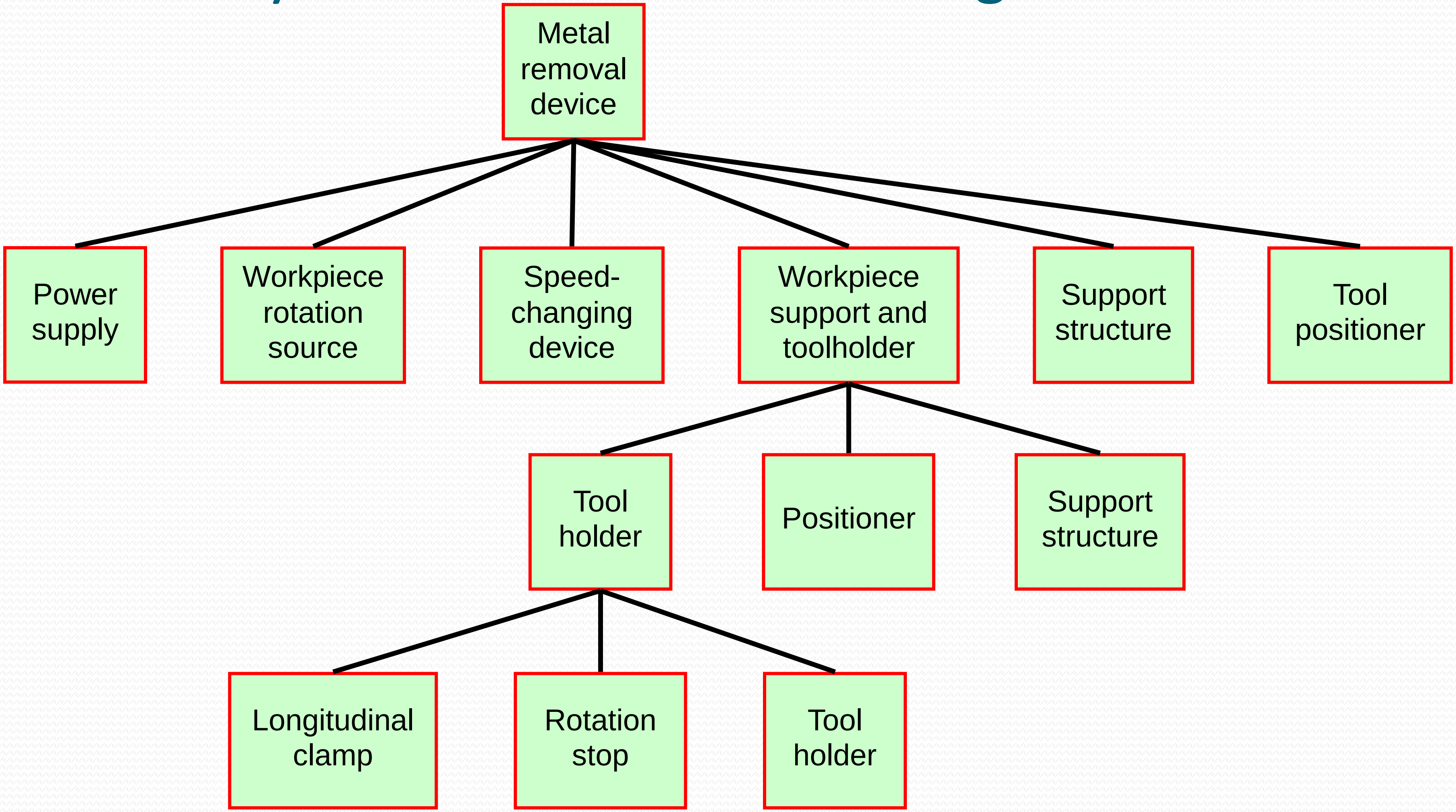
Axiom 2: *The information axiom*

Minimize the information content.

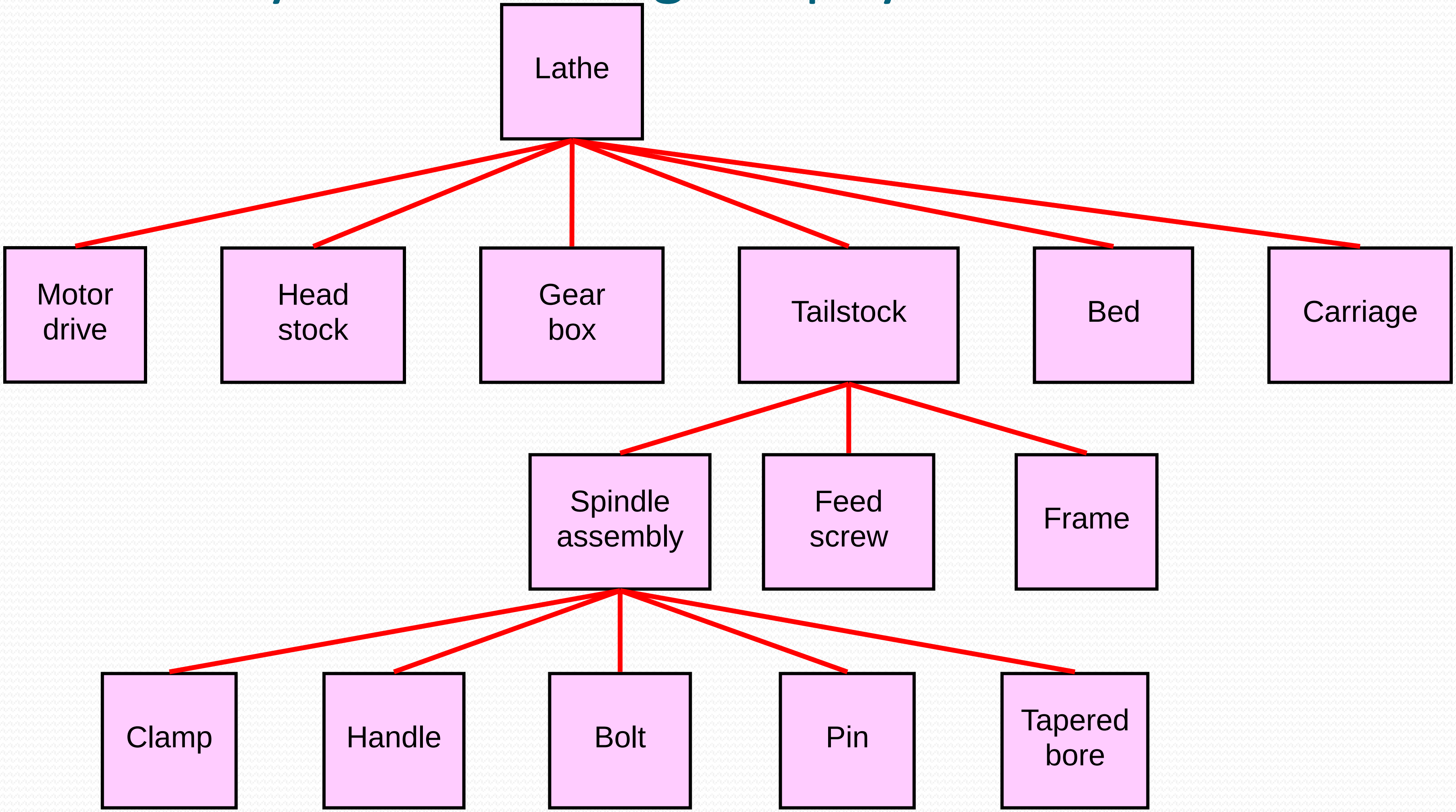
Mapping process of Suh’s concept



Hierarchy of FRs for a metal cutting lathe



Hierarchy of lathe design in physical domain



7 corollaries are derived from the 2 axioms mentioned before

Corollary 1:	*Decoupling of a coupled design* Decouple or separate parts or aspects of a solution if FRs are coupled or become interdependent in the proposed design.
Corollary 2:	*Minimize FRs* Minimize the number of FRs and constraints.
Corollary 3:	*Integration of physical parts* Integrate design features in a single physical part if FRs can be independently satisfied in the proposed solution.
Corollary 4:	*Use of standardization* Use standardized or interchangeable parts if the use of these parts is consistent with the FRs and constraints.
Corollary 5:	*Use of symmetry* Use symmetric shapes and/or arrangement if they are consistent with the FRs and constraints. Symmetrical parts require less information to manufacture and to orient in assembly.
Corollary 6:	*Largest tolerance* Specify the largest allowable tolerance in stating FRs.
Corollary 7:	*Uncoupled design with less information* Seek an uncoupled design that requires less information than coupled designs in satisfying a set of FRs.

Evaluation

Comparison Based on Absolute Criteria

1. Evaluation based on judgment of feasibility of the design. Concept should be into one of three categories:
    a) It is not feasible? Next question is "Why is it not feasible?"
    b) It is conditional –it might work if something else happen?
    c) Looks as if it will work, then it seems worth to work further.

Comparison Based on Absolute Criteria

2. Evaluation based on assessment of technology readiness. The technology used in the design must be mature enough not to need any additional research. Their indicators are
   a) Can the technology be manufactured with known processes?
   b) Are the critical parameters that control the function identified?
   c) Are the safe operating latitude and sensitivity of the parameters known?
   d) Have the failure modes been identified?
   e) Does hardware exist that demonstrates positive answers to the above four questions?

Comparison Based on Absolute Criteria

3. Evaluation based on go-no-go screening of the customer requirements.
   - After a design concept has passed filters 1 and 2, the emphasis shifts to establishing whether it meets the customer requirements framed in the QFD
   - Each requirement must be transformed into a question to be addressed to each concept.
   - The questions should be answerable as either yes (go), maybe (go), or no (no-go).
   - The emphasis is not on a detail examination but on eliminating any design concepts that clearly not able to meet an important customer requirement.

Pugh's Concept Selection Method

1. Choose the criteria by which the concepts will be evaluated
2. Formulate the decision matrix
3. Clarify the design concept
4. Choose the datum concept
5. Run the matrix
6. Evaluate the rating
7. Establish a new datum and rerun the matrix
8. Plan further work
9. Second working session

Example of CD case

Criterion	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Std. CD case
Mfg. cost	S	-	S	-	S	
Easier opening	+	S	S	S	+	
Easier to remove leaflet	S	S	-	+	-	
Easier to remove CD	S	+	+	+	S	D
Hinge doesn't come apart	+	S	S	S	+	A
Stacking stability	S	S	S	S	+	T
More secure locking	+	S	+	+	+	U
Fits hand better	S	+	+	S	+	M
Σ +	3	2	3	3	5	
Σ -	0	1	1	1	1	
Σ S	5	5	4	4	2	

Measurement Scales

Pairwise Comparison method **Assume 5 design objectives to be compared**

Design objectives	A	B	C	D	E	Row total
A	-	1	0	0	1	2
B	0	-	1	1	1	3
C	1	0	-	0	0	1
D	1	0	1	-	1	3
E	0	0	1	0	-	1
						10

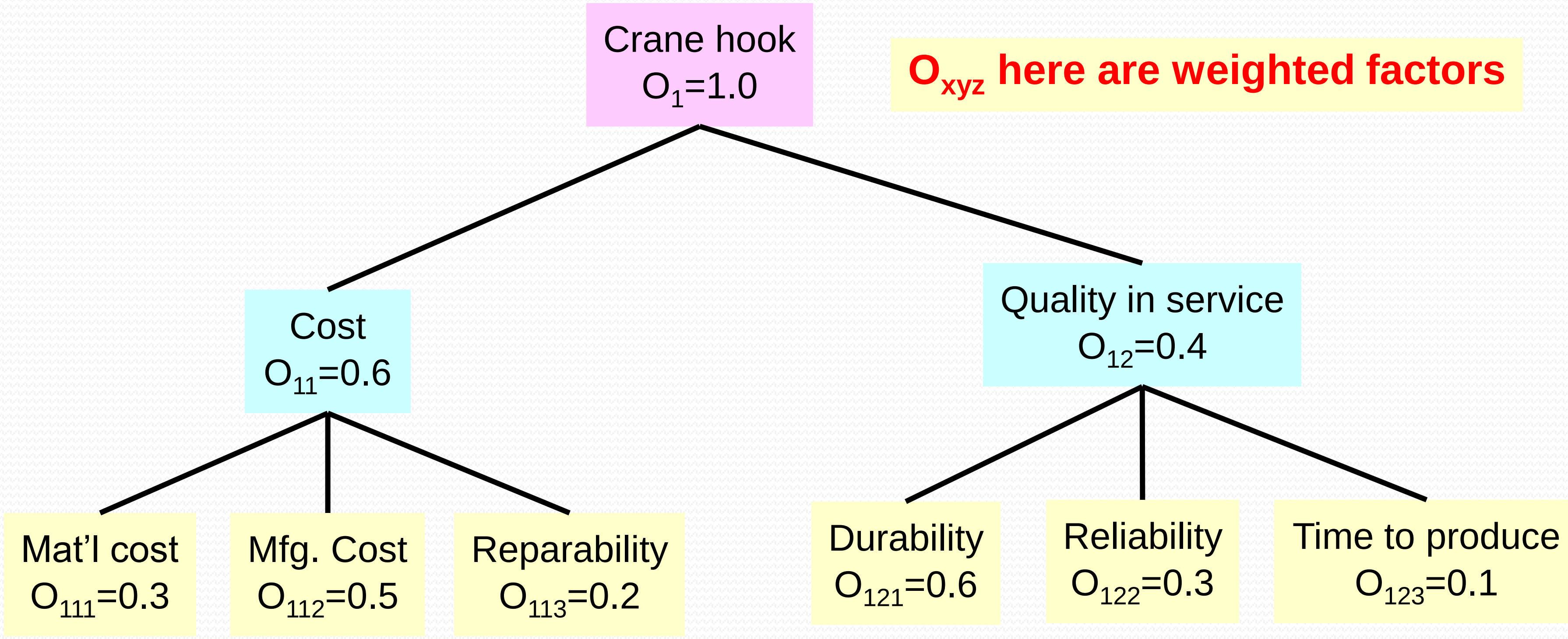
Weighted Decision Matrix

11-point scale	Description	5-point scale	Description
0	Totally useless solution	0	Inadequate solution
1	Very inadequate solution		
2	Weak solution	1	Weak
3	Poor solution		
4	Tolerable solution	2	Satisfactory
5	Satisfactory solution		
6	Good solution with a few drawback		
7	Good solution	3	Good
8	Very good solution		
9	Excellent (exceed the requirement)	4	Excellent
10	Ideal solution		

Example of Steel Crane Hook

A heavy steel crane hook, for use in supporting ladles filled with molten steel as they are transported through the steel mill, is being designed. Three concepts have been proposed: (1) built-up from steel plates, welded together; (2) built-up from steel plates, riveted together; (3) a monolithic cast-steel hook.

The design criteria investigated are (1) material cost, (2) manufacturing cost, (3) time to produce another if one fails. (4) durability, (5) reliability, (6) reparability.



Weighted Decision Matrix for a steel hook

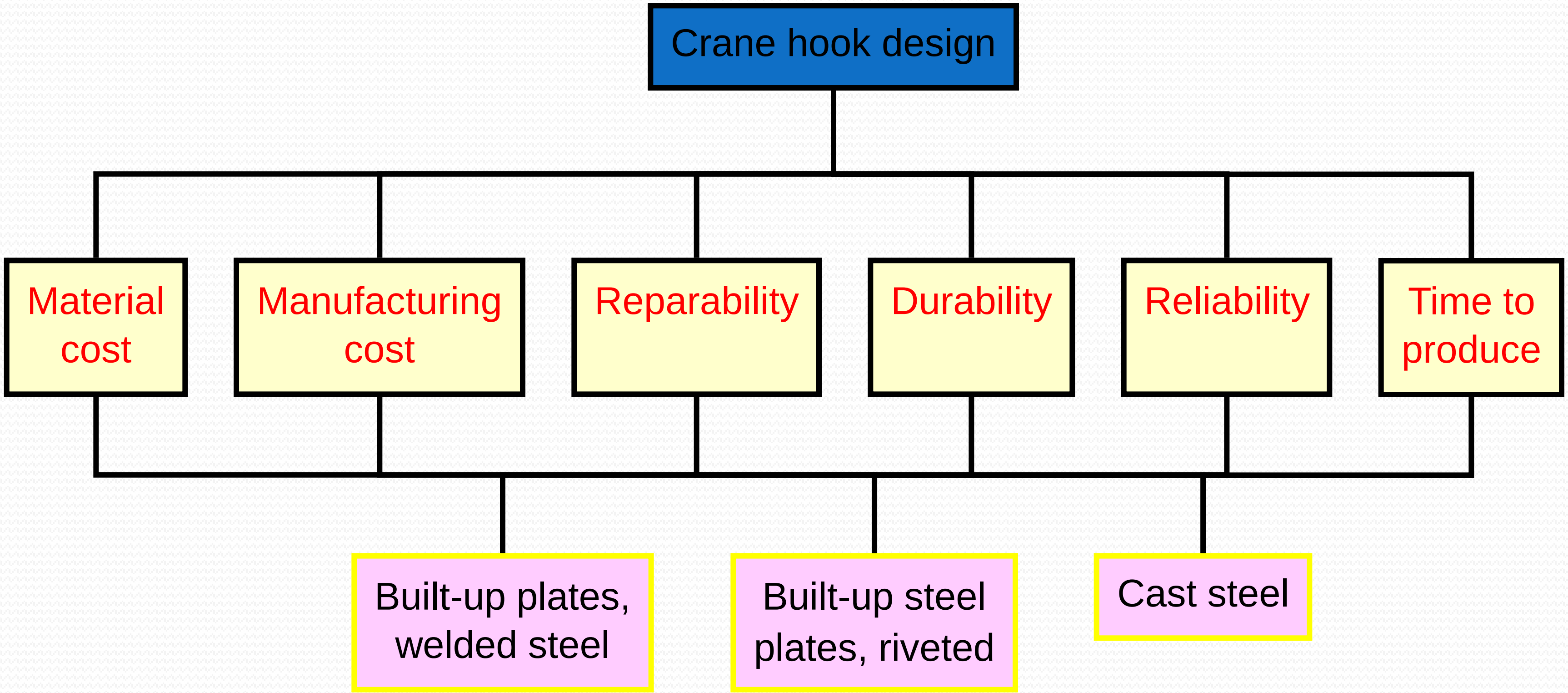
Design criterion	Weight factors	Unit	Built-up plates welded			Built-up plates riveted			Cast steel hook		
			Mag.	Score	Rating	Mag.	Score	Rating	Mag.	Score	Rating
Material cost	0.18	¢/lb	60	8	1.44	60	8	1.44	50	9	1.62
Mfg. cost	0.60	$	2500	7	2.1	2200	9	2.70	3000	4	1.20
Reparability	0.12	Exp	Good	7	0.84	Excell.	9	1.08	Fair	5	0.60
Durability	0.24	Exp.	High	8	1.92	High	8	1.92	Good	6	1.44
Reliability	0.12	Exp.	Good	7	0.84	Excell.	9	1.08	Fair	5	0.60
Time to produce	0.04	Hr.	40	7	0.28	25	9	0.36	60	5	0.20
					7.42			8.58			5.66

Mag. = Magnitude
Exp. = Experience
Excell. = Excellent

Analytical Hierarchy Process, AHP

- Multicriteria decision process introduced by Saaty
- Suited to hierarchically structural system
- Can work with both numerical and intangible and subjective factors
- Use pairwise comparison of the alternatives

Example of crane hook design using AHP approach



Hierarchical structure of a crane hook design

Saaty's fundamental scale for pairwise comparison

Intensity of importance	Definition	Description
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Judgment and experience slightly favor one activity over another
5	Strong importance	Judgment and experience strongly favor one activity over another
7	Very strong	An activity is favored very strongly over another
9	Extreme importance	The evidence favoring one activity over another is of the highest possible
2, 4, 6, 8	These rating are used to compromise between the above values.	

Square matrix to determine weighting factors

	Material cost	Manufacturing cost	Reparability	Durability	Reliability	Time to produce
Material cost	1	1/5	3	1/5	3	7
Manufacturing cost	5	1	7	3	3	7
Reparability	1/3	1/7	1	1/5	1/3	5
Durability	5	1/3	5	1	3	7
Reliability	1/3	1/3	3	1/3	1	7
Time to produce	1/7	1/7	1/5	1/7	1/7	1
Total	11.8	2.14	19.2	4.87	10.47	34

Normalized values for square matrix

	Material cost	Manufacturing cost	Reparability	Durability	Reliability	Time to produce	
Material cost	0.085	0.424	0.028	0.424	0.028	0.012	1
Manufacturing cost	0.093	0.467	0.065	0.154	0.154	0.065	1
Reparability	0.156	0.364	0.052	0.260	0.156	0.010	1
Durability	0.041	0.616	0.041	0.205	0.068	0.029	1
Reliability	0.286	0.286	0.031	0.286	0.095	0.013	1
Time to produce	0.206	0.206	0.147	0.206	0.206	0.029	1
Total	**0.867**	**2.363**	**0.364**	**1.535**	**0.707**	**0.158**	**6**
Weighting factor (AVG)	**0.144**	**0.394**	**0.061**	**0.256**	**0.118**	**0.026**	**1**

Now construct the decision matrix using previous values given.

	Built-up welded plates	Built-up riveted plates	Cast	
Manufacturing cost	2500	2200	3000	$/crane hook
	400	454	333	Reciprocal x 10^{-6}
	0.34	0.38	0.28	Fraction of total

	Built-up welded plates	Built-up riveted plates	Cast	
Reparability	6	10	1	Ranking
	0.35	0.59	0.06	Fraction of total

Durability	Welded plate		Riveted plate		Cast		Total	Rating (Avg.)
Welded plate	1.00	0.23	1/3	0.22	3.00	0.33	0.78	0.26
Riveted plate	3.00	0.69	1.00	0.65	5.00	0.56	1.90	0.63
Cast	1/3	0.08	1/5	0.13	1.00	0.11	0.32	0.11
Total	4.33	1.00	1.53	1.00	9.00	1.00	3.00	1.00

Final Decision Matrix for the Crane Hook Problem

Design criterion	Weight factor	Welded plate	Riveted plate	Cast	Welded plate	Riveted plate	Cast
Material cost	0.14	0.31	0.31	0.38	0.043	0.043	0.053
Manufacturing cost	0.39	0.34	0.38	0.28	0.133	0.148	0.109
Reparability	0.06	0.35	0.59	0.06	0.021	0.035	0.004
Durability	0.25	0.26	0.63	0.11	0.065	0.157	0.027
Reliability	0.12	0.33	0.43	0.24	0.040	0.052	0.029
Time to produce	0.03	0.31	0.49	0.20	0.008	0.013	0.005
Total	1.00				0.31	0.45	0.23

Then riveted plate is the most appropriate alternative for this design