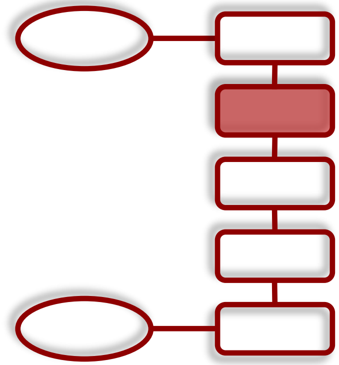
ENGR 110 / 112 – Design I

Design Process

Design Selection

Instructor: Dr. Flavio Firmani

Conceptual Design



Here we generate concepts of alternative designs.

Input: *Revised problem statement*

List of final objectives (criteria)

List of final constraints

Tasks: *v)* ~~*Establish functions*~~ (e.g., function-means tree)

vi) Establish requirements or specifications

vii) ~~*Generate alternative designs*~~ (e.g., morphological charts)

Outputs: *Design and Functional Specifications*

Alternative conceptual designs

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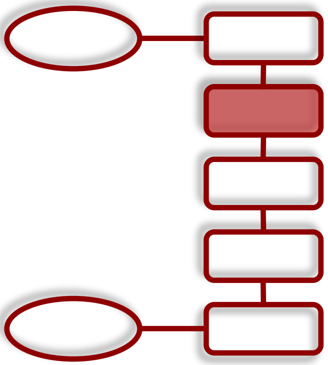
Specifications



There are three types of requirements or specifications: Functional Specifications, Design Specifications and Procedural Specifications:

Functional Specifications: It characterizes the desired behavior or performance of the designed product or system.

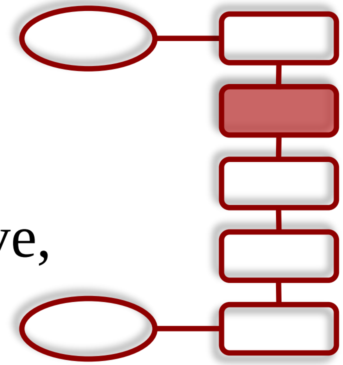
Functions describe what the product ***must do*** in order to realize the stated objectives.

"A step on a ladder is safe if it will support 300 lbs."

LOAD CAPACITY*	DESCRIPTION	CSA CODE	ANSI CODE
200 lbs./91 kg	Household - Light Duty	Grade 3	Type III
225 lbs./102 kg	Tradesman and Farm - Medium Duty	Grade 2	Type II
250 lbs./113 kg	Construction and Industrial - Heavy Duty	Grade 1	Type I
300 lbs./136 kg	Construction and Industrial - Heavy Duty	Grade 1A	Type IA
375 lbs./170 kg	Construction and Industrial - Heavy Duty	Grade 1AA	Type IAA

*Includes user and materials

Specifications



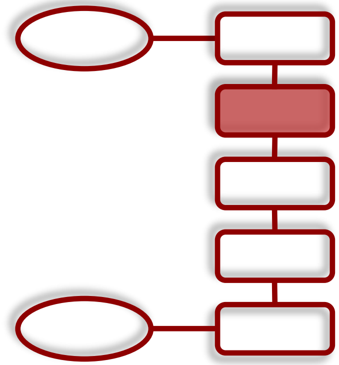
Design Specifications: These specifications are prescriptive, as they specify values of attributes that the designed product must meet to be successful. Design Specifications are associated with the verb ***to be***.

"A step on a ladder is safe if it is made from Grade A fir, the spacing between steps shall not be less than 8in nor more than 18in, and each step must be attached to the frame in a full-width groove slot at each end"

Procedural Specifications: These specifications identify specific procedures or methods to be used in calculating the attributes or behaviors.

"A step on the ladder is safe if its maximum bending stress is computed from $\sigma_{max} = {}^{Mc}/_{I}$ and is such that σ_{max} does not exceed σ_{allow}".

Specifications

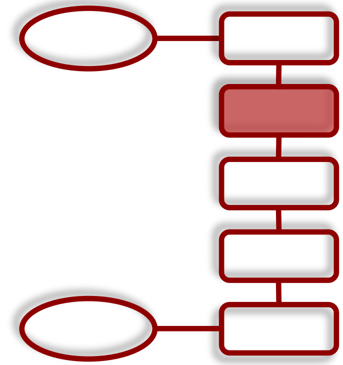


In general, specifications are very large documents that list all the requirements for each category (General, Mechanical, Electrical, Safety, etc.)

The document is generally structured in a way that is easy to be accessed. It is recommended to have the following structure:

- **Scope**: What is this document for?
- **Intended Audience**: Team, Supervisors, Client
- **Classification Scheme**: Classify specifications with tags. Each company uses their own notation for the tags.

Example



Following the example of the ladders, the Occupational Safety and Health Administration of the US, uses the following standards to define the specifications of commercial ladders. Link

Part 1926 – Safety and Health Regulations for Construction

Subpart 1053 – Ladders

Tag: 1926.1053(a)(1)(i)

a – Defines whether general (a) or use (b)

1 – Lists the categories of the specifications, 1, 2, 3, etc.

i - Lists the specifications for that particular category.

Example

1926.1053(a)*General*. The following requirements apply to all ladders as indicated, including job-made ladders.

1926.1053(a)(1)Ladders shall be capable of supporting the following loads without failure:

1926.1053(a)(1)(i)Each self-supporting portable ladder: At least four times the maximum intended load, except that each extra-heavy-duty type 1A metal or plastic ladder shall sustain at least 3.3 times the maximum intended load. The ability of a ladder to sustain the loads indicated in this paragraph shall be determined by applying or transmitting the requisite load to the ladder in a downward vertical direction. Ladders built and tested in conformance with the applicable provisions of appendix A of this subpart will be deemed to meet this requirement.

1926.1053(a)(1)(ii)Each portable ladder that is not self-supporting: At least four times the maximum intended load, except that each extra-heavy-duty type 1A metal or plastic ladders shall sustain at least 3.3 times the maximum intended load. The ability of a ladder to sustain the loads indicated in this paragraph shall be determined by applying or transmitting the requisite load to the ladder in a downward vertical direction when the ladder is placed at an angle of 75 1/2 degrees from the horizontal. Ladders built and tested in conformance with the applicable provisions of appendix A will be deemed to meet this requirement.

1926.1053(a)(1)(iii)Each fixed ladder: At least two loads of 250 pounds (114 kg) each, concentrated between any two consecutive attachments (the number and position of additional concentrated loads of 250 pounds (114 kg) each, determined from anticipated usage of the ladder, shall also be included), plus anticipated loads caused by ice buildup, winds, rigging, and impact loads resulting from the use of ladder safety devices. Each step or rung shall be capable of supporting a single concentrated load of at least 250 pounds (114 kg) applied in the middle of the step or rung. Ladders built in conformance with the applicable provisions of appendix A will be deemed to meet this requirement.

1926.1053(a)(2)Ladder rungs, cleats, and steps shall be parallel, level, and uniformly spaced when the ladder is in position for use.

…. (follows)

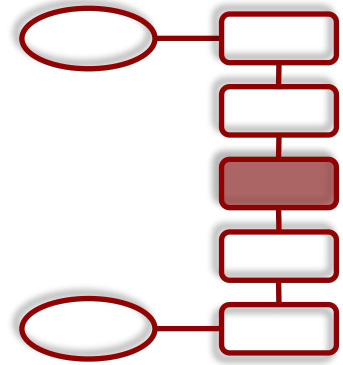
1926.1053(b)*Use*. The following requirements apply to the use of all ladders, including job-made ladders, except as otherwise indicated:

1926.1053(b)(1)When portable ladders are used for access to an upper landing surface, the ladder side rails shall extend at least 3 feet (.9 m) above the upper landing surface to which the ladder is used to gain access; or, when such an extension is not possible because of the ladder's length, then the ladder shall be secured at its top to a rigid support that will not deflect, and a grasping device, such as a grabrail, shall be provided to assist employees in mounting and dismounting the ladder. In no case shall the extension be such that ladder deflection under a load would, by itself, cause the ladder to slip off its support.

1926.1053(b)(2)Ladders shall be maintained free of oil, grease, and other slipping hazards.

… (continues)

Preliminary Design



Here we identify the principal attributes of the design concepts to make a selection.

Input: *Alternative conceptual designs*

Design and Functional Requirements (specs)

Tasks: *viii) Metrics for final criteria*

ix) Select a design alternative

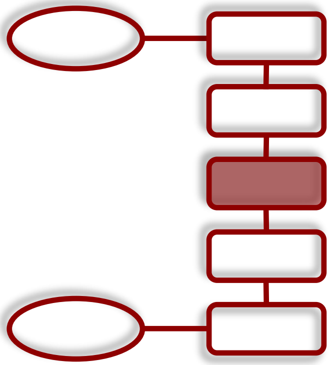
x) Analyze chosen design

xi) Test and evaluate chosen design

Outputs: *Selected design*

Test and evaluation results

Preliminary Design



Design Selection

How can we select the ‘best’ design among various concepts?

Selecting the ‘best’ design is not simple as there could be many designs that are valid.

Creating prototypes of all the concepts and then testing them is not feasible (budget and time). Thus, it is necessary to establish faster and inexpensive methods to ensure the proper selection of a design. Two qualitative methods that compare candidate designs are

- *Quality Function Deployment (House of Quality)*
- *Numerical Decision Matrix*

Preliminary Design

House of Quality

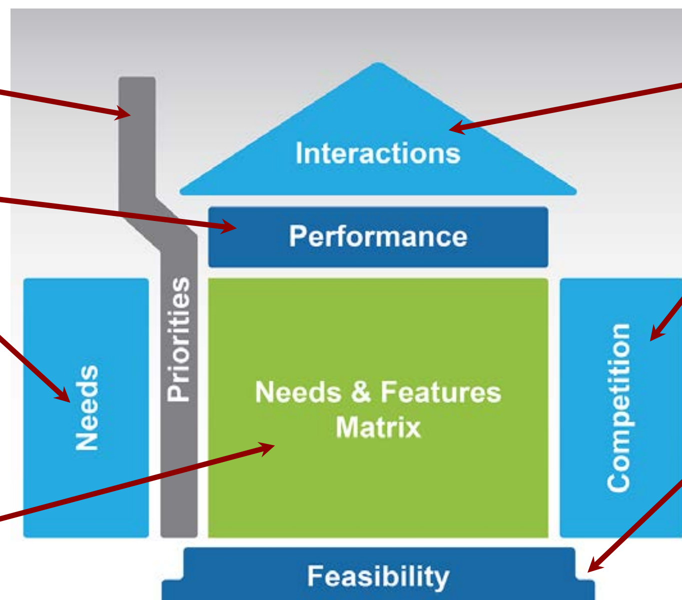
The house of quality is used to recognize design improvements. Defines the relation of customer needs (criteria) with technical requirements, establishes design interactions, compares product against competition, and targets of the technical requirements.

Criteria Weights

Technical requirements

Client/consumer criteria

Relationship between technical and consumer requirements



Interaction between technical requirements

Comparison with other designs

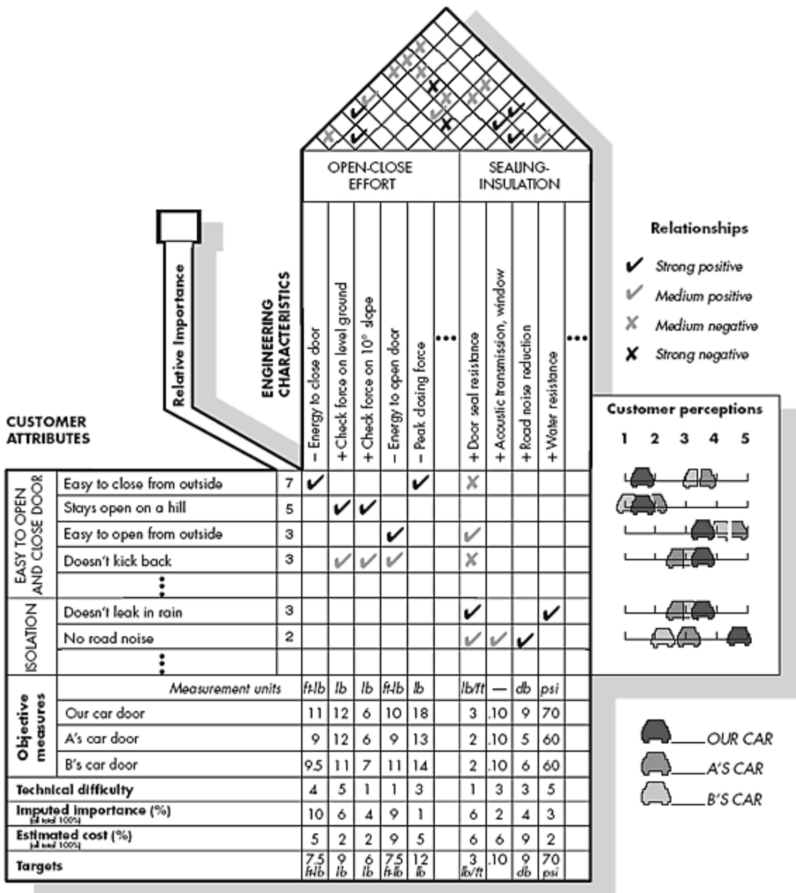
Targets of design requirements

Retrieved Oct 17, from https://www.mindflowdesign.com/

Preliminary Design

House of Quality Examples

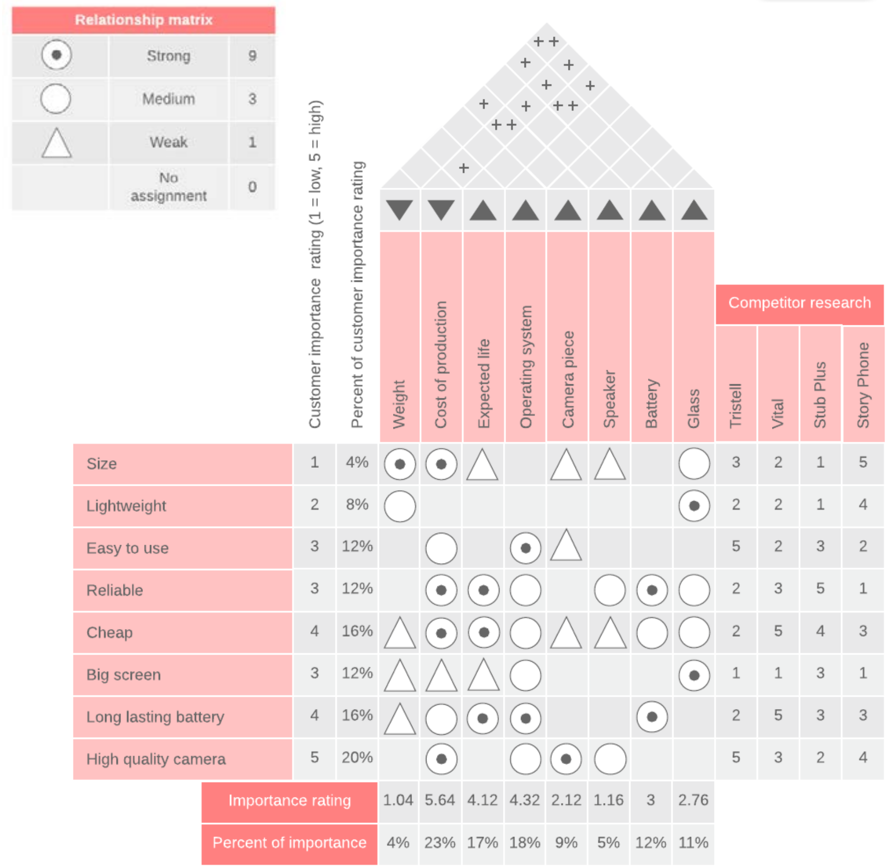
Car Doors



		Relative Importance	− Energy to close door	+ Check force on level ground	+ Check force on 10° slope	− Energy to open door	− Peak closing force	...	+ Door seal resistance	+ Acoustic transmission, window	+ Road noise reduction	+ Water resistance	...
EASY TO OPEN AND CLOSE DOOR	Easy to close from outside	7	✔				✔		✗				
	Stays open on a hill	5		✔	✔								
	Easy to open from outside	3				✔			✔				
	Doesn't kick back	3		✔	✔	✔			✗				
	⋮												
ISOLATION	Doesn't leak in rain	3							✔			✔	
	No road noise	2							✔	✔	✔		
	⋮												
Objective measures	Measurement units		ft-lb	lb	lb	ft-lb	lb		lb/ft	—	db	psi	
	Our car door		11	12	6	10	18		3	.10	9	70	
	A's car door		9	12	6	9	13		2	.10	5	60	
	B's car door		9.5	11	7	11	14		2	.10	6	60	
Technical difficulty			4	5	1	1	3		1	3	3	5	
Imputed importance (%) (of total 100%)			10	6	4	9	1		6	2	4	3	
Estimated cost (%) (of total 100%)			5	2	2	9	5		6	6	9	2	
Targets			7.5 ft-lb	9 lb	6 lb	7.5 ft-lb	12 lb		3 lb/ft	.10	9 db	70 psi	

Retrieved Oct 2021, from Harvard Business Reviews

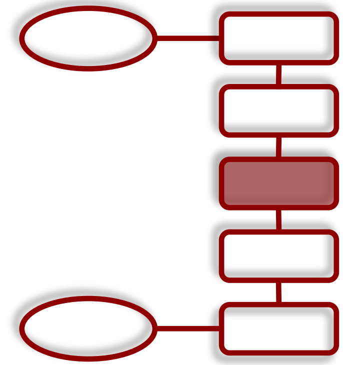
Smartphone



	Customer importance rating (1 = low, 5 = high)	Percent of customer importance rating	Weight ▼	Cost of production ▼	Expected life ▲	Operating system ▲	Camera piece ▲	Speaker ▲	Battery ▲	Glass ▲	Tristell	Vital	Stub Plus	Story Phone
Size	1	4%	⊙	⊙	△		△	△		○	3	2	1	5
Lightweight	2	8%	○							⊙	2	2	1	4
Easy to use	3	12%		○		⊙	△				5	2	3	2
Reliable	3	12%		⊙	⊙	○		○	⊙	○	2	3	5	1
Cheap	4	16%	△	⊙	⊙	○	△	△	○	○	2	5	4	3
Big screen	3	12%	△	△	△	○				⊙	1	1	3	1
Long lasting battery	4	16%	△	○	⊙	⊙			⊙		2	5	3	3
High quality camera	5	20%		⊙		○	⊙	○			5	3	2	4
Importance rating			1.04	5.64	4.12	4.32	2.12	1.16	3	2.76				
Percent of importance			4%	23%	17%	18%	9%	5%	12%	11%				

Retrieved Oct 2021, from lucidchart.com

Preliminary Design



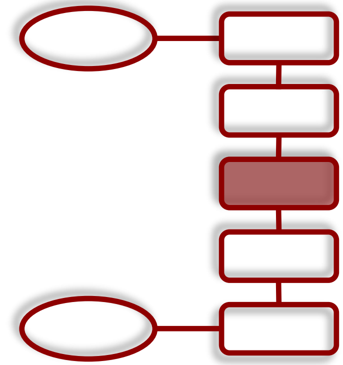
Numerical Decision Matrix

In this course, we employ numerical decision matrices, also referred to as Weighted Objective Charts.

In order to complete the numerical decision matrix, we need:

- List of design criteria, around eight (criteria tree)
- Rank importance of criteria (weighted criteria tree)
- Scales of the degree in which the criteria of our design are achieved (metrics)
- Design concepts (morphological charts)

Preliminary Design



Metrics

Recalling definition of design objectives / criteria
"expressions of desired attributes and behavior
that are quantifiable expectations of performance."

Metrics are scales that indicate how well a particular design performs in relation to a design criteria. In order to develop consistent metrics, we need to

- Identify the units and the scale that is appropriate to *measure*.
- Identify a method of assessing the value of a particular design (e.g., statistics, researching, testing, simulating)

In the following examples, we will use a scale with five levels of performance, in some cases more levels is recommended.

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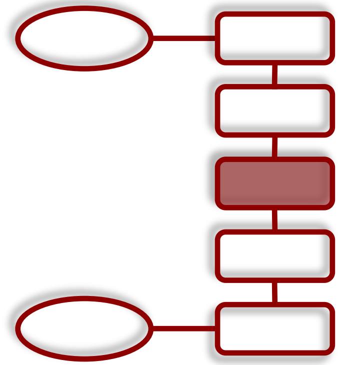
Preliminary Design



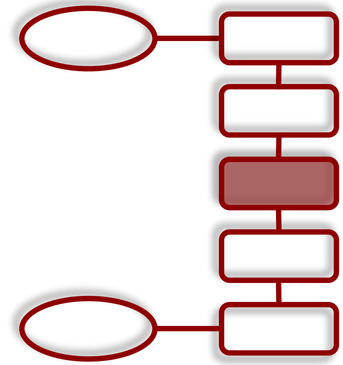
Example of Metrics

Cost of a Detached House (at least 3 2) in Metro Victoria (Capital Regional District). Unit of measurement dollars ($).

Scale	Qualitative Description	Scale
1	Very Expensive	>$1.50M
2	Expensive	$1.20M - $1.50M
3	Average	$1.00M – $1.20M
4	Below Average	$800K – $1.00M
5	Inexpensive	<$800K

Assessing value: asking price, market value, BC assessment, etc.

Example



Applying metrics to the design objectives / criteria

Objective: *Beverage container should be environmentally friendly*

Metric:		
	Completely reusable	1.00
	Material is recyclable	0.90
	Material is easily disposable	0.50
	Material is hard to dispose	0.10
	Material is hazardous waste	0

Objective: *Beverage container should be easy to distribute*

Metric:		
	Very easy to pack and stack	1.00
	Easy to pack and stack	0.75
	Can be packed and stacked	0.50
	Hard to pack and stack	0.25
	Very hard to pack and stack	0

Objective: *Beverage container should preserve taste*

Metric:		
	Will not change taste	1.00
	Will slightly change	0.75
	Will noticeably change	0.50
	Will change taste a lot	0.25
	Will be undrinkable	0

Example

Morphological Charts

List functions (same level):

List all the means

Contain beverage:

Can, Bottle, Bag, Box

Material of container (taste, strength):

Aluminum, Plastic, Glass, Waxed Cardboard, Lined Cardboard, Mylar Films.

Provide access to juice

Pull-Tab, Inserted Straw, Twist-Top, Tear Corner, Unfold Container, Zipper.

Display product information:

Shape, Labels, Color

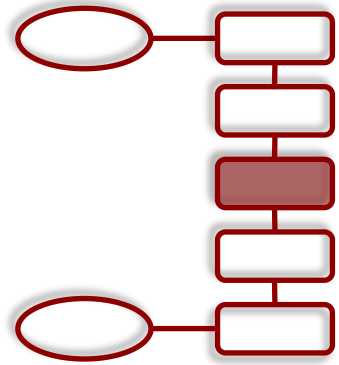
Manufacturing sequence:

Concurrent, Serial

MEANS FEATURE/ FUNCTION	1	2	3	4	5	6
Contain Beverage	Can	Bottle	Bag	Box	••••	••••
Material for Drink Container	Aluminum	Plastic	Glass	Waxed Cardboard	Lined Cardboard	Mylar Films
Mechanism to Provide Access to Juice	Pull Tab	Inserted Straw	Twist Top	Tear Corner	Unfold Container	Zipper
Display of Product Information	Shape of Container	Labels	Color of Material	••••	••••	••••
Sequence Manufacture of Juice, Container	Concurrent	Serial	••••	••••	••••	••••

FIGURE 5.1 A morphological (morph) chart for the beverage container design problem. The *functions* that the device must serve are listed in the left most column. For each function, the *means* by which it can be implemented are arrayed along a row to the function's right. A conceptual design or scheme can be constructed by linking one means for each of the five identified functions, thus assembling a design in the classic "Chinese menu" style. (See Figure 5.2.)

Example



Generate concepts with Morphological charts

MEANS FEATURE/ FUNCTION	1	2	3	4	5	6
Contain Beverage	Can	Bottle	Bag		Box	••••
Material for Drink Container	Aluminum	Plastic	Glass	Waxed Cardboard	Lined Cardboard	Mylar Films
Mechanism to Provide Access to Juice	Pull Tab	Inserted Straw	Twist Top	Tear Corner	Unfold Container	Zipper
Display of Product Information	Shape of Container	Labels	Color of Material	••••	••••	••••
Sequence Manufacture of Juice, Container	Concurrent	Serial	••••	••••	••••	••••

MEANS FEATURE/ FUNCTION	1	2	3	4	5	6
Contain Beverage	Can	Bottle	Bag	Box	••••	••••
Material for Drink Container	Aluminum	Plastic	Glass	Waxed Cardboard	Lined Cardboard	Mylar Films
Mechanism to Provide Access to Juice	Pull Tab	Inserted Straw	Twist Top	Tear Corner	Unfold Container	Zipper
Display of Product Information	Shape of Container	Labels	Color of Material	••••	••••	••••
Sequence Manufacture of Juice, Container	Concurrent	Serial	••••	••••	••••	••••

Example

Evaluation Matrices (Weighted Objective Charts)

Criteria weighted tree

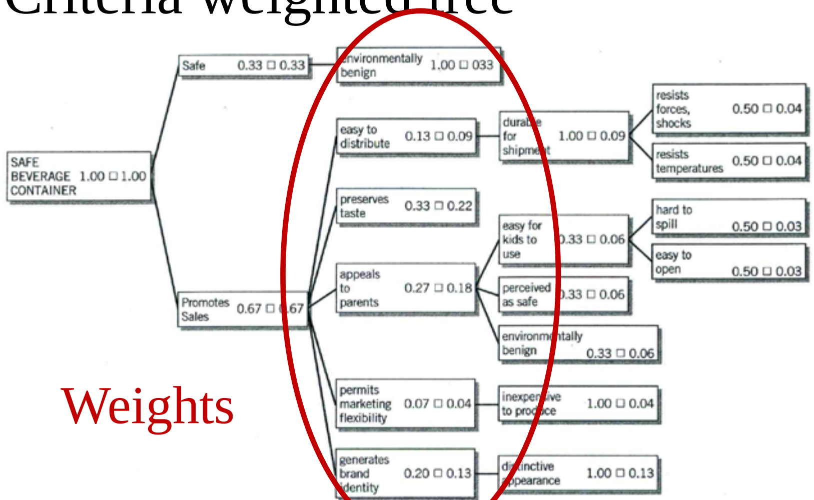


Figure 3.6 A weighted objectives tree for the design of a new beverage container, here reflecting the values of the BJIC company.

Assessment of concept (metrics)

Objective: *Beverage container should be environmentally benign*

Metric:	Completely reusable	1.00
	Material is recyclable	0.90
	Material is easily disposable	0.50
	Material is hard to dispose	0.10
	Material is hazardous waste	0

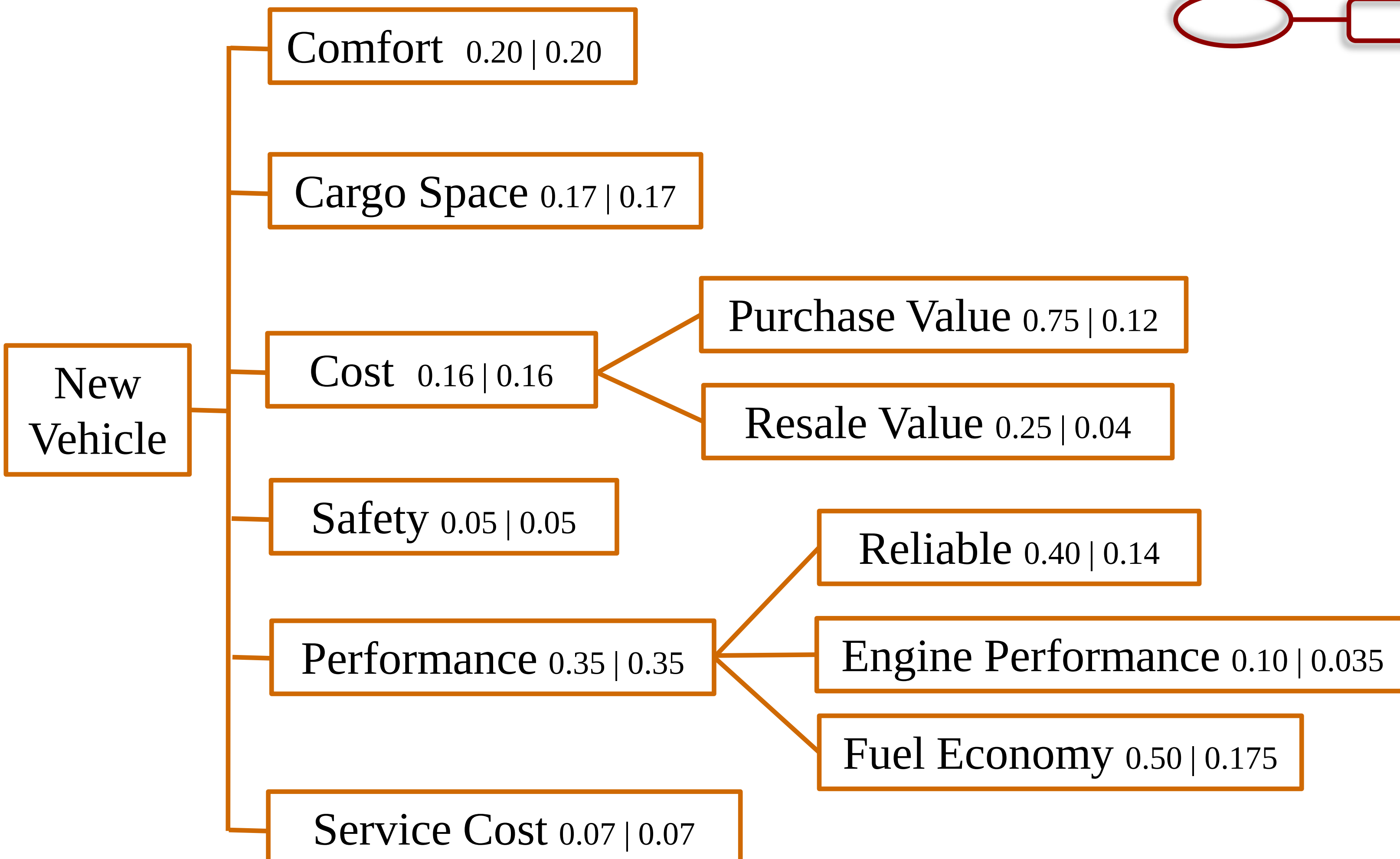
Figure 6.4 A numerical evaluation matrix for the beverage container design problem. This chart reflects BJIC's values in terms of the weights assigned to each objective, which are the same as those in the weighted objectives tree of Figure 3.6. They also correspond to the results given in the pairwise comparison chart of Figure 3.4 (b).

DESIGN CONSTRAINTS/ OBJECTIVES	Weight (%)	Glass bottle, with twist-off cap	Aluminum can, with pull-tab	Polyethylene bottle, with twist-off cap	Mylar bag, with straw
C: No sharp edges		✗	✗		
C: No toxin release					
C: Preserves quality					
O: Environmentally benign	33			0.9 × 33% 29.7%	0.1 × 33% 3.3%
O: Easy to distribute	09			0.5 × 9% 4.5%	0.6 × 9% 5.4%
O: Preserves taste	22			0.9 × 22% 19.8%	1.0 × 22% 22%
O: Appeals to parents	18			0.8 × 18% 14.4%	0.5 × 18% 9.0%
O: Permits marketing flexibility	04			0.5 × 4% 2.0%	0.5 × 4% 2.0%
O: Generates brand identity	13			0.2 × 13% 2.6%	1.0 × 13% 13%
TOTALS	99			73.0%	54.7%

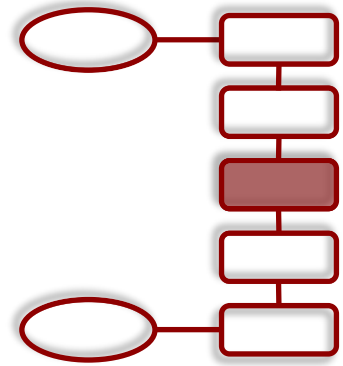
Prof. Flavio Firmani

Example

Weighted Criteria Tree



Example

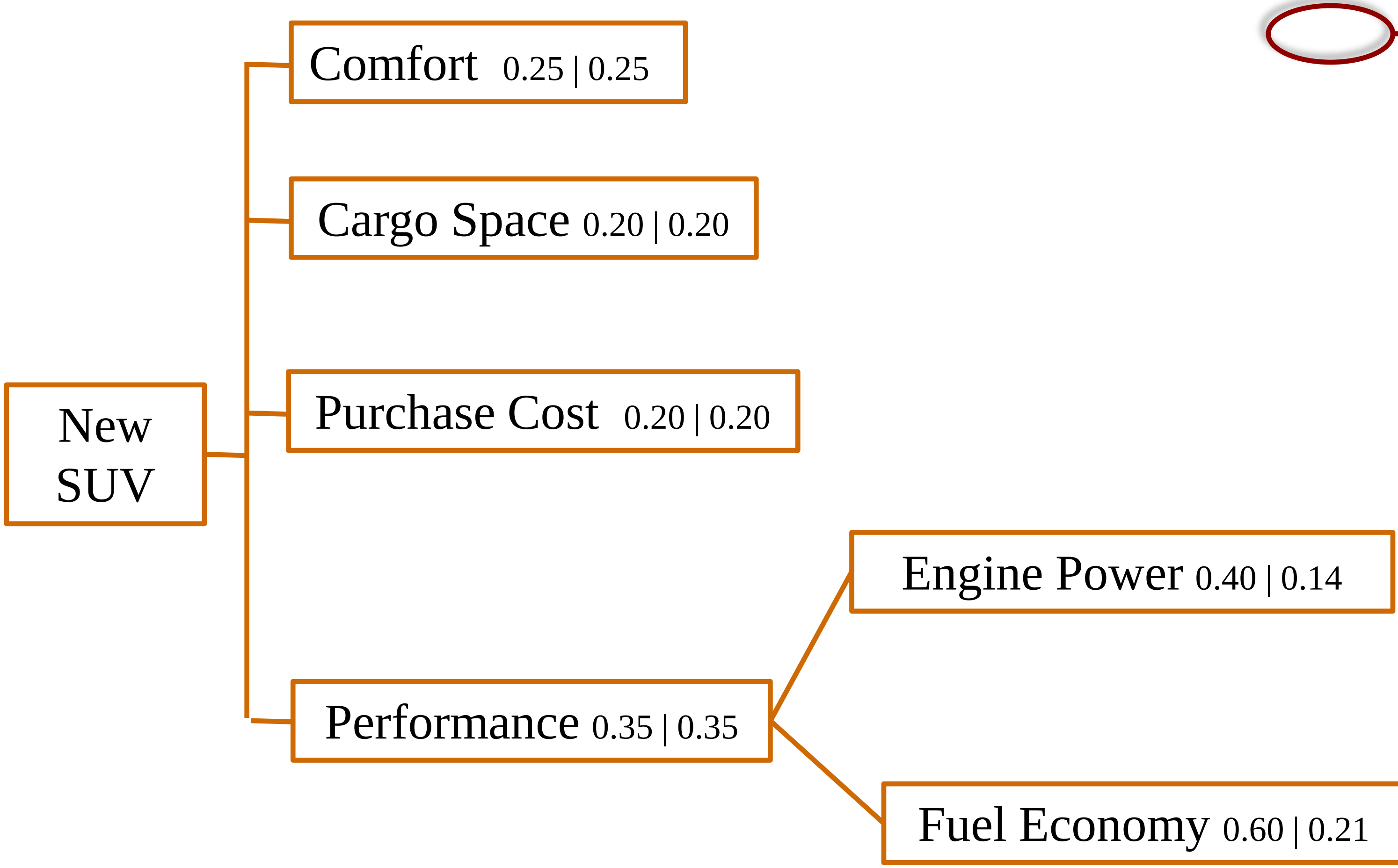


On your phone, identify SUV models that must have (Constraints):

- Third Row (7/8 passengers)
- AWD
- Below or around $40K

Example

Class Activity (Reduced criteria for the activity)



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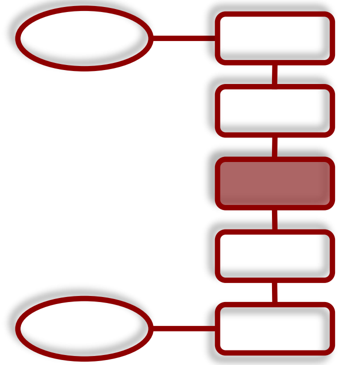
Example



Metrics

Purchase Cost ($)

Scale	Qual. Descrip.	Scale
1	Very Expensive	>$40K
2	Expensive	$37K - $40K
3	Average	$34K – $37K
4	Below Average	$30K – $34K
5	Inexpensive	<$30K

Cargo Space (Liters)

Scale	Qual. Descrip.	Scale
1	Compact	<2000 L
2	Below Average	2000L - 2200L
3	Average	2200L – 2500L
4	Spacious	2500L – 2800L
5	Very Spacious	>2800L

Comfort (Edmunds Rate[1])

Scale	Qual. Descrip.	Scale
1	Uncomfortable	<6.5
2	Below Average	7.0-7.5
3	Average	7.5-8.0
4	Comfortable	8.0-8.5
5	Very Comfortable	>8.5

[1]Average Comfort and Driving

Fuel Economy[2] (L/100km)

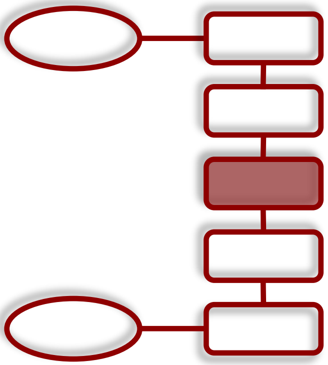
Scale	Qual. Descrip.	Scale
1	Inefficient	>11.0
2	Below Average	10.0-11.0
3	Average	9.0-10.0
4	Above Average	8.0-9.0
5	Fuel Efficient	< 8.0

[2] Combined (City and Hwy)

Horsepower (HP)

Scale	Qual. Descrip.	Scale
1	Lack of Power	<150
2	Below Average	150-200
3	Average	200-250
4	Above Average	250-300
5	Powerful	>300

Example

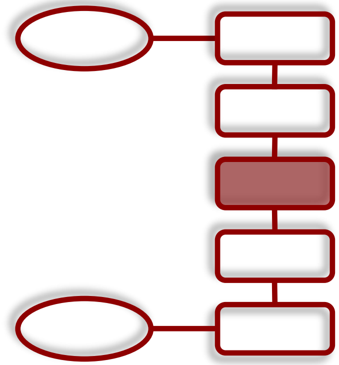


Numerical Decision Matrix

Evaluate different candidates (Score = Weight × Value)

Criteria	Weight	Car A		Car B		Car C		Car D		Car E		Car F	
		Value	Score	Value	Score	Value	Score	Value	Score	Value	Score	Value	Score
Cost	0.20												
Cargo	0.20												
Comfort	0.25												
Fuel Economy	0.21												
Power	0.14												
Total Score													

Example

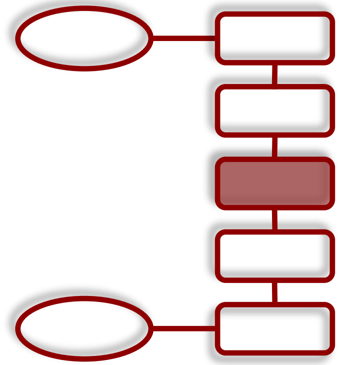


Candidates

Vehicles with 3^{rd}-row of seats, AWD, and under $40K.

Candidate	Cost	Cargo	Comfort	Fuel Economy	Power
	($)	(L)	(Rating)	(L/100km)	(HP)
Mazda CX-9	39,900	2,017	8.25	10.5	250
Subaru Ascent	37,000	2,440	7.5	11	260
Mitsubishi Outlander	32,000	2,256	7.75	8.9	181
Kia Sorrento	36,000	2,139	8	9.7	191
Chevrolet Traverse	39,500	2,781	7.75	11.6	310
VW Atlas	40,000	2,740	8	10.8	235

Example



Numerical Decision Matrix

Evaluate different candidates (Score = Weight × Value)

Criteria	Weight	Mazda CX-9		Subaru Ascent		Mitsubishi Outlander		Kia Sorrento		Chevrolet Traverse		Volkswagen Atlas	
		Value	Score	Value	Score	Value	Score	Value	Score	Value	Score	Value	Score
Cost	0.20	2	0.40	3	0.60	4	0.80	3	0.60	2	0.40	2	0.40
Cargo	0.20	2	0.40	3	0.60	3	0.40	2	0.40	4	0.80	4	0.80
Comfort	0.25	4	1.00	3	0.75	3	0.75	4	1.00	3	0.75	4	1.00
Fuel Economy	0.21	2	0.42	2	0.21	4	0.84	3	0.63	1	0.21	2	0.42
Power	0.14	4	0.56	4	0.56	2	0.28	2	0.28	5	0.70	3	0.42
Total Score			**2.38**		**2.93**		**3.27**		**2.91**		**2.86**		**3.04**