9b.
Supplier Selection using Multi-criteria Decision Making

Multi-criteria Decision Making

- Often, we need to make decisions and to choose among numerous alternatives, using more than one criteria.
- At the national / regional economy level: employment, health, education, investments, …
- At the individual company level: where to place a store/factory/warehouse, selecting a supplier, …
- At the personal level: selecting a university to study, a career, a course, a car, a holiday resort, …

Quantitative vs. Qualitative

- All decisions involve both factors
- Thus, what is important is the ability to synthesize these factors within the decision making process

Why these decision are complicated?

- Difficult to frame the problem and identify criteria
- Quantitative criteria
  - Not always easy to come up with a number you are certain about
- Qualitative criteria
  - Difficult to assign a numerical value
  - Difficult to prioritize and give relative weights
- Contradictory criteria
  - Trade-offs between criteria
- Subjective judgments

Methods

- Goal Programming Method
- Multi-Weighted scoring Model
- Analytical Hierarchy Process (AHP)

Method 1: Goal Programming

- The existence of multiple objectives is common-place!
- Often they are conflicting. They cannot be combined. There have to be trade-offs!
- There is a concept of satisfying! Some constraints are "soft", i.e., they can be "slightly violated"
- Goal programming is applied to linear problems.

Example: Program scheduling

- Planning a new course on Stevens' BI&A program
- Total course should be approximately equal & should not exceed 100 hrs (class + lab)
- A classroom hr = 12 minutes of team-work (t-w) + 19 minutes of individual work (i-w)
- A lab hr = 29 minutes of t-w + 11 minutes of i-w

TWO GOALS:

- Each student should spend as close as possible to 1/4 of maximum program time in team work.
- Each student should spend, if possible, 1/3 of the time on individual problem solving.

Goal Programming Approach

- Let x1 = hrs. of classroom work
  x2 = hrs. of laboratory work

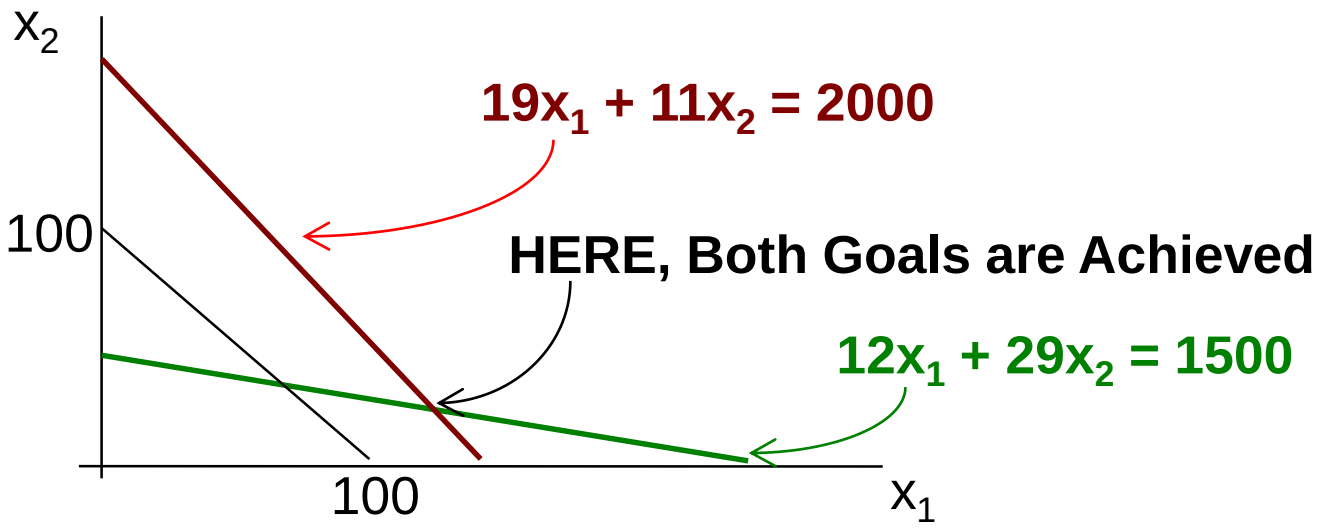
- In Goal Programming there are two types of constraints:
  - System constraints ..... cannot be violated.
  - Goal constraints ..... may be violated.

- Constraints of our problem:

  - $x1 + x2 \leq 100$ ..... system constraint
  - $12x1 + 29x2 \approx 0{,}25\,(100)(60) = 1500$... goal constraint
  - $19x1 + 11x2 \approx (100)(60)/3 = 2000$..... goal constraint.

Goal Programming Model

- $x_1 + x_2 \leq 100$
- $12x_1 + 29x_2 \approx 0{,}25\,(100)(60) = 1500$
- $19x_1 + 11x_2 \approx (100)(60)/3 = 2000$



Objective: Min the deviations

- Re-formulate the goal constraints:
- $12x_1 + 29x_2 + u_1 - v_1 = 1500$
- $19x_1 + 11x_2 + u_2 - v_2 = 2000$
- $x_1, x_2, u_1, u_2, v_1, v_2 \geq 0$

$$\text{Min } Z = u_1 + v_1 + u_2 + v_2$$

s.t.

$$\begin{aligned} x_1 + x_2 &\leq 100 \\ 12x_1 + 29x_2 + u_1 - v_1 &= 1500 \\ 19x_1 + 11x_2 + u_2 - v_2 &= 2000 \\ x_1, x_2, u_1, v_1, u_2, v_2 &\geq 0 \end{aligned}$$

Note: We are indifferent about the deviations
Otherwise, put different weights

Multi-Weighted Scoring Model

- 1st Step: Determination of appraisal / evaluation criteria for the selection of supplier
- 2nd Step: Creation of Evaluation Tables + Selection of appropriate weights for each criterion
  - The weights rank the criteria according to their importance / value
  - In some cases, weights can also be used as the maximum credits/points one can get for each criterion
- 3rd Step: Evaluation of Suppliers for each criterion

Multi-Weighted Scoring Model

- **The weights typically depend on our goals (e.g. a strategic goal of our organization) or the particular characteristics of the item / service we want to procure**
  - For example, if we want to buy a common item widely available in the market, we will put high weights on criteria related to fast deliveries or criteria related to the reduction of processing costs
  - For example, if we want to buy an item with complex specifications, we will put high weights on criteria related to quality
- **The weight can be expressed as a percentage or simply as a liner distribution from 1 to 10**

Multi-Weighted Scoring Model

- Design, development and production of a specialized package for the storage of small sized and highly sensitive archeological founds

Rating of Suppliers				
Criteria	Max Value	Supplier		
		A	B	Γ
Technical				
- Understanding of the problem	10	**10**	8	7
- Technical approach	20	**18**	16	15
- Production capacity	5	**4**	5	4
- Functional requirements	3	**2**	3	2
- Quality requirements	2	**1**	2	2
Sub-total	40	**35**	34	30
- Responsiveness	20	**18**	15	12
- Price	20	**16**	20	2
- Financial stability	10	**10**	8	8
- Application of well known standards	10	**9**	8	7
Total	100	**88**	85	59

Multi-Weighted Scoring Model

- Combination of the multi-weighted scoring model with other considerations, such as motivation, building of long terms relationships etc….

Analytic Hierarchy Process

- A common problem in multicriteria decision making is to select the weight that each criterion would have, according to its relative importance
- This problem does not exist with the AHP
- The AHP assumes that we can do pair-wise comparisons
  - among the criteria for their relative importance
  - among the alternative choices for each criterion separately

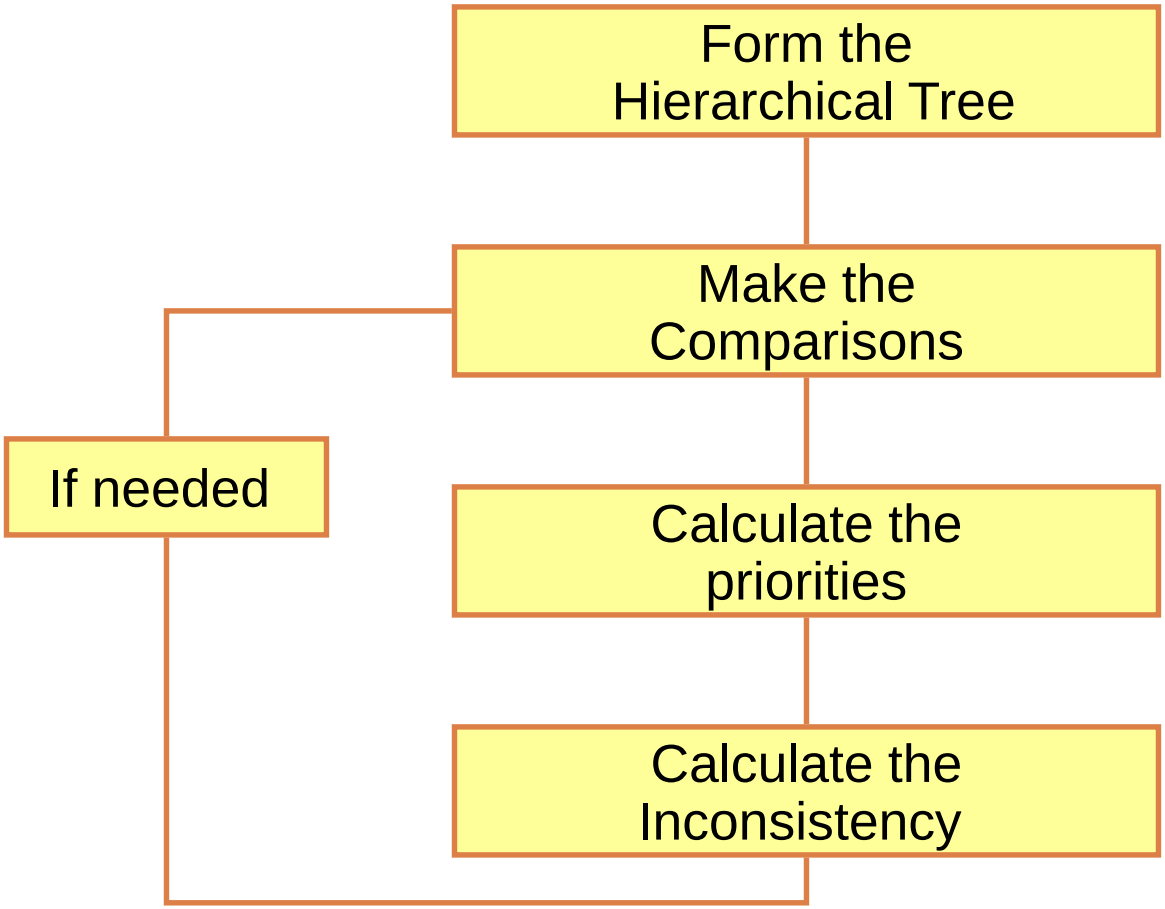
Benefits of the AHP

- Facilitates the setting of criteria, goals, strategy
- Facilitates the consensus in formulating strategy
- Facilitates the acceptance and hence the implementation of the proposed strategy

Methodology

- Information is decomposed into a hierarchy of alternatives and criteria
- Information is then synthesized to determine relative ranking of alternatives
- Both qualitative and quantitative information can be compared using informed judgments that derive weights and priorities

AHP Steps

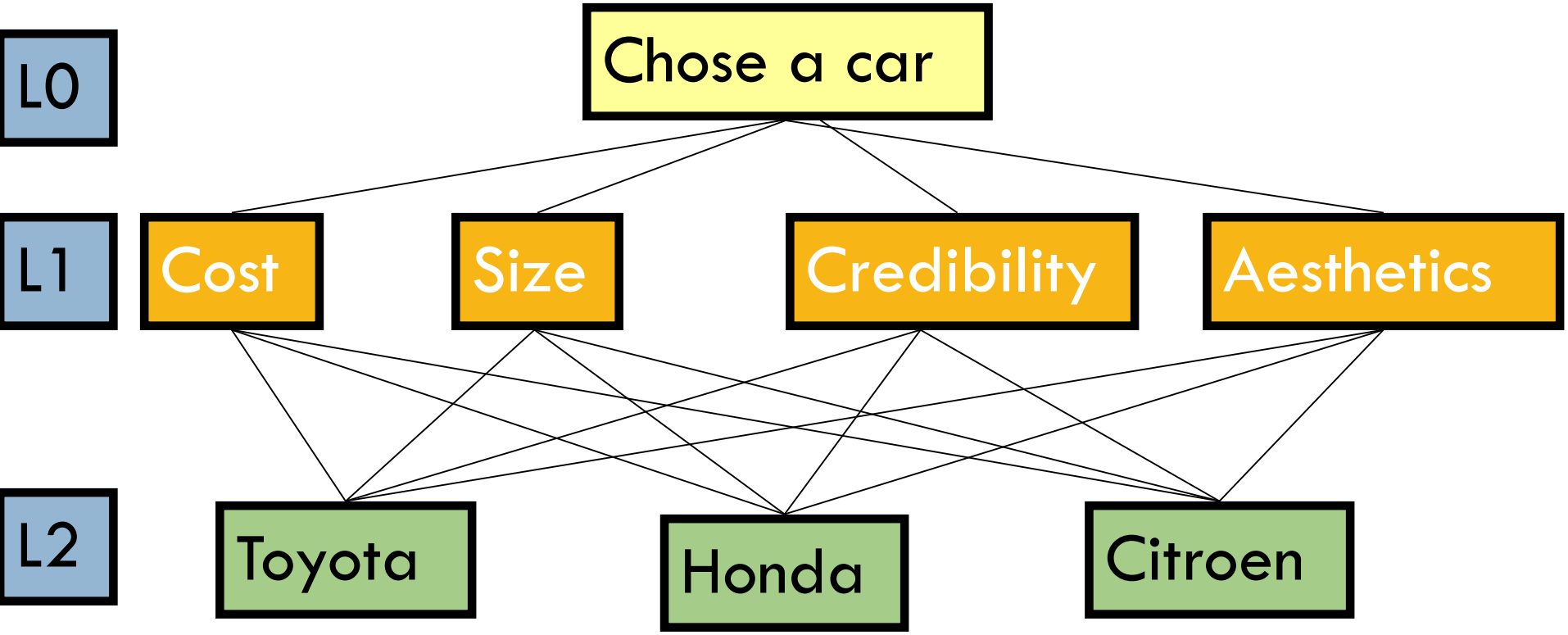

Form the Hierarchical Tree
Make the Comparisons
If needed
Calculate the priorities
Calculate the Inconsistency

Establish the Hierarchical Tree

Example: Selecting a Supplier

- Objective: Supplier selection
- Alternatives
  - Honda
  - Toyota
  - Citroen
- Criteria
  - Cost
  - Size
  - Credibility
  - Aesthetics

Step 1: Hierarchical Tree

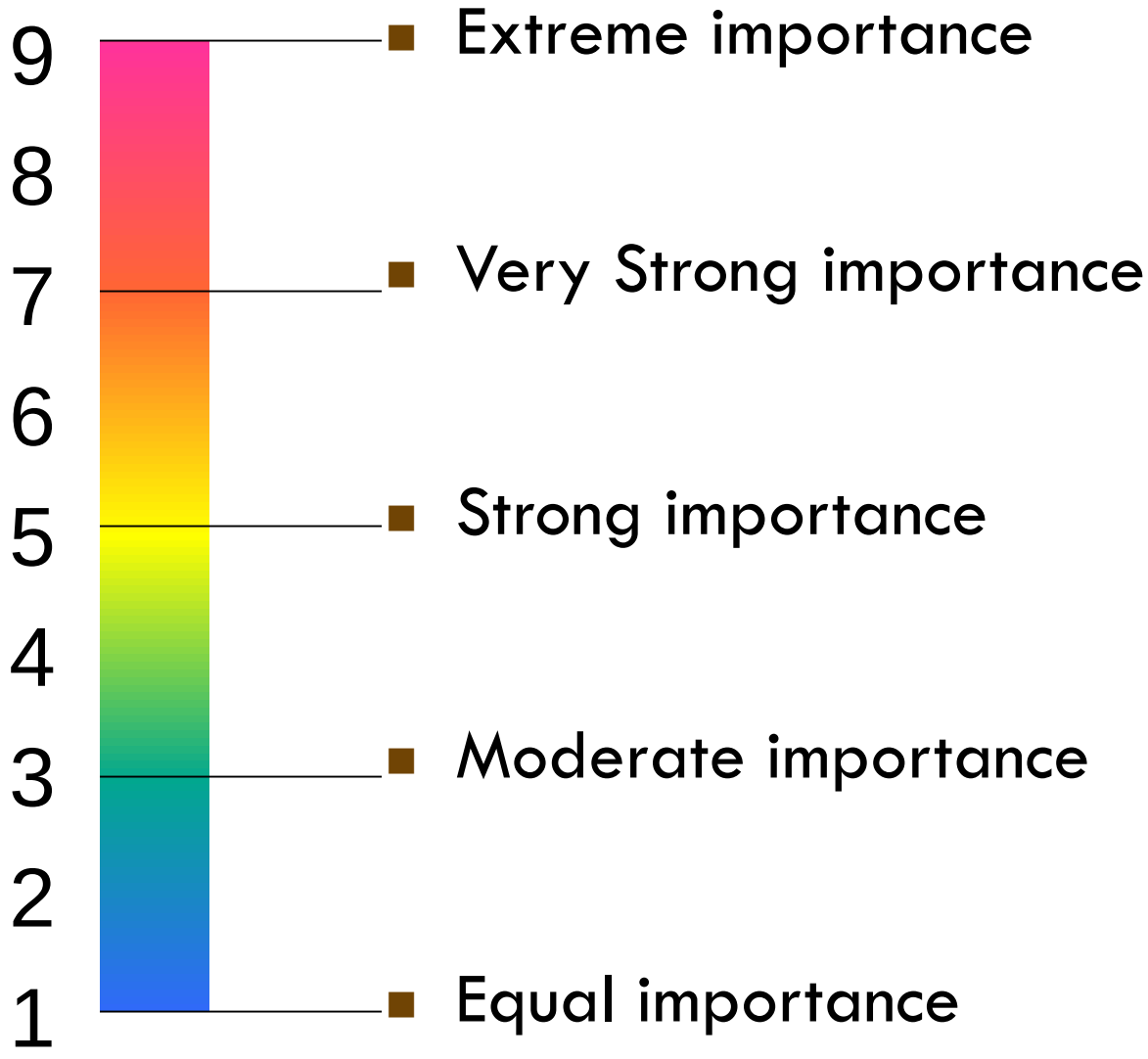


Step 2: Comparisons

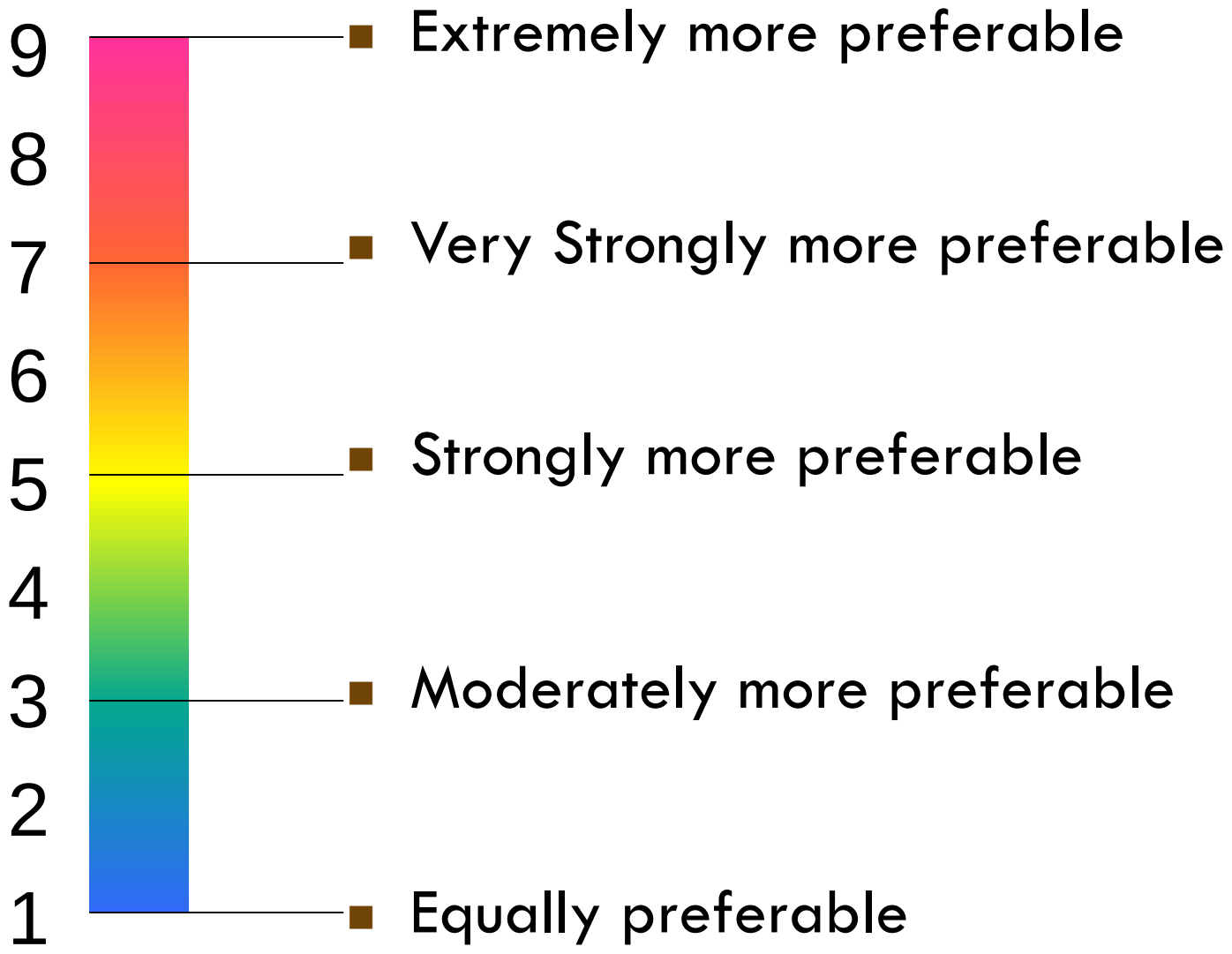
Starting from the bottom, the items of every level are compared with each other with respect to the items of the previous levels.

- Each car (Level 2) is compared with all the others with respect to the items of the Level 1 (criteria).
- Each criterion (Level 1) is compared with the others with respect to its importance in solving the problem that is defined in Level 0.

Scale - Criteria



Scale - Alternatives



Step 2.1: Pair-wise comparisons of alternatives with respect to each criterion

- Pair-wise comparisons of cars with respect to each criterion (credibility, aesthetics, etc.) in order to establish priorities of the alternatives with respect to each criterion.
  - Compare cars with respect to credibility
  - Compare cars with respect to size
  - Compare cars with respect to aesthetics
  - Compare cars with respect to cost

Comparing Cars w.r.t. Credibility

With respect to **credibility**:
Toyota is **equally** preferable to Honda
Honda is **moderately** more preferable to Citroen
Toyota is **moderately** more preferable to Citroen."

How do we calculate these priorities?

Credibility				
	Toyota	Honda	Citroen	Priorities
Toyota	**1**	1	3	0.43
Honda	1	**1**	3	0.43
Citroen	1/3	1/3	**1**	0.14

Calculating priorities

- Add the elements of each column
- Divide the element of each column with the sum of its column
- We calculate the average across each row. This average is the priority of each criterion that is expressed by the corresponding line

	T	H	C
T	1	1	3
H	1	1	3
C	0.33	0.33	1
sum	2.33	2.33	7

Original preferences matrix

T	H	C
0.43	0.43	0.43
0.43	0.43	0.43
0.14	0.14	0.14

Normalized matrix

Relative Priorities
0.43
0.43
0.14

Comparing Cars w.r.t. Size

With respect to **size**:
Toyota is **equally** dominant to Citroen
Toyota is **moderately** dominant to Honda
Citroen is **moderately** dominant to Honda.

Size				
	Toyota	Honda	Citroen	Priorities
Toyota	**1**	3	1	0.43
Honda	1/3	**1**	1/3	0.14
Citroen	1	3	**1**	0.43

Comparing Cars w.r.t. Aesthetics

With respect to **aesthetics**:
Toyota is **moderately to strongly** dominant to Citroen
Toyota is **moderately** dominant to Citroen
Honda is **equally to moderately** dominant to Honda

Aesthetics				
	Toyota	Honda	Citroen	Priorities
Toyota	**1**	4	3	0.63
Honda	1/4	**1**	2	0.22
Citroen	1/3	1/2	**1**	0.15

Comparing Cars w.r.t. Cost

With respect to **cost**:
Toyota is **equally** dominant to Honda
Toyota is **equally to moderately** dominant to Citroen
Honda is **equally** dominant to Citroen

Cost				
	Toyota	Honda	Citroen	Priorities
Toyota	**1**	1	2	0.41
Honda	1	**1**	1	0.33
Citroen	1/2	1	**1**	0.26

Step 2.2: Pair-wise comparisons of criteria

- **Cost** is equally to moderately more important than credibility, moderately more important than size, and moderately more important than aesthetics
- **Credibility** is equally to moderately less important than cost, moderately more important than size, and moderately more important than aesthetics
- **Size** is moderately less important than cost, moderately less important than credibility, and equally to moderately less important than Aesthetics
- **Aesthetics** is moderately less important than cost, moderately less important than credibility, and moderately less important than size

Step 2.2: Pair-wise comparisons of criteria

Cost is equally to moderately more important than credibility

Cost is moderately more important than size

CRITERIA	Cost	Credibility	Size	Aesthetics
Cost	1	2	3	3
Credibility	1/2	1	3	3
Size	1/3	1/3	1	1/2
Aesthetics	1/3	1/3	2	1

Calculating the Priorities of the criteria

- We add the items of each column
- We divide each item with the sum of its column
- We calculate the average across each row. This average is the priority of each criterion that is expressed by the corresponding line

CRITERIA	Cost	Credibility	Size	Aesthetics
Cost	1	2	3	3
Credibility	0.50	1	3	3
Size	0.33	0.33	1	0.50
Aesthetics	0.33	0.33	2	1
Sum	**2.17**	**3.67**	**9.00**	**7.50**

CRITERIA	Cost	Credibility	Size	Aesthetics	Average
Cost	0.46	0.54	0.33	0.40	0.43
Credibility	0.23	0.27	0.33	0.40	0.31
Size	0.15	0.09	0.11	0.07	0.11
Aesthetics	0.15	0.09	0.22	0.13	0.15

Overall table of partial priorities

Alternatives	Criteria			
	Cost 0.43	Credibility 0.31	Size 0.11	Aesthetics 0.15
Toyota	0.43	0.43	0.43	0.62
Honda	0.33	0.43	0.14	0.22
Citroen	0.26	0.14	0.43	0.15

Total Priorities

- Total Priority of Car_i = SUM OVER ALL 4 CRITERIA OF [(Priority of a $CRITERION_i$) × (Priority of Car_i for that criterion)]

  = Priority of COST × Priority of Car_i for cost +

  + Pr CREDIBILITY × Priority of Car_i for credibility +

  + Pr SIZE × Priority of Car_i for size +

  + Pr AESTHETICS × Priority for Car_i for aesthetics

- Ranking the alternatives

  Toyota=45%, Honda=33%, Citroen=22%

Inconsistency

- Often, there is inconsistency in our own preferences and in our estimations, a fact that could reduce the credibility of our results
- With the AHP we can calculate the level of inconsistency for every priority table (λ_{max})
- The inconsistency level should not exceed 10%

Causes of Inconsistency

- Clerical Error
  - The most common cause of inconsistency. Could go undetected for quite some time
- Lack of information
- Lack of concentration
  - Get tired during the judgment process, or simply lose interest
- Real World is not always consistent!
  - Team A wins team B, team B wins team C, and then … team C wins team A!
  - Due to random fluctuations, or underlying causes, or both
- Inadequate Model Structure
  - Some times, extreme judgments might be necessary in the pair-wise comparisons

Calculating the Inconsistency

- We add the elements of every column and multiply the sum with the priority of the corresponding criterion.
- We add the products for all columns
- If **A** is the resulting sum and **n** is the number of criteria, then the inconsistency index **λmax** is equal to

$$\lambda max=(A-n)/(n-1)$$

- The inconsistency index should be calculated for each one of the comparison matrices

Calculating the Inconsistency

	T	H	C	Priorities
T	1	1	3	0.43
H	1	1	3	0.43
C	0.33	0.33	1	0.14
sum	2.33	2.33	7	

- $A=0.233\times0.43+0.233\times0.43+7\times0.14=2.9838$
- $\lambda max=(2.9838-3)/(3-1)=0.0081<0.1$
- Repeat for every priority table

Evaluating the AHP

- Allows the Decision Makers to split the original - complex - problem into a hierarchical structure
- Uncertainties can be included
- Synthesizes data, experience, insight in a logical way
- Enables Decision Makers to derive ratio scale priorities
- It's an easy to use and easy to understand method – but … getting the 2-by-2 comparisons for each alternative and for each criterion could be time consuming
- It provides us with a graphical representation of the problem
- Transparency in the decision making process!

Application Areas

- Supply Chain Management
- Strategic planning
- Resource allocation
- Production planning
- Source selection, program selection
- Business strategy
- Etc.

Applications of AHP for the Appraisal and Evaluation of Suppliers / Sub-contractors

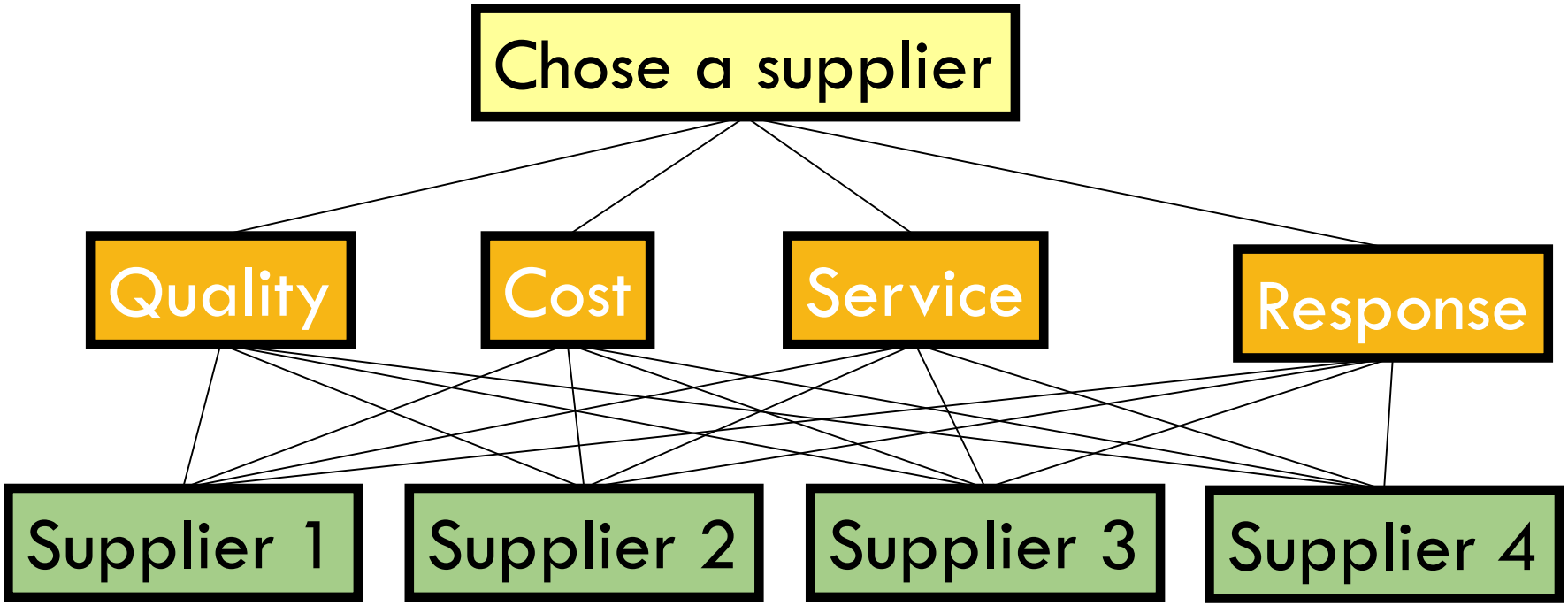
Analytical Hierarchy Process

- Create a set of suppliers and criteria
- Again, first, we construct a matrix where all suppliers / criteria are assessed in pairs, using the range from 1 to 9. Remember:
  - aij = 1 if both criteria i and j are equally important
  - aij = 3 if i is slightly more important compared to j
  - aij = 5 if i is more important compared to j
  - aij = 7 if i is much more important compared to j
  - aij = 9 if i is highly important compared to j.
- Second, we normalize each matrix by dividing each element with the total sum of the corresponding column
- Third, we calculate the average values of each row
- We repeat for all suppliers / criteria.

Step 1: Hierarchical Tree

Example:

- We have 4 suppliers, i.e., S1, S2, S3 and S4
- We will evaluate them according to 4 criteria: quality, cost, service and response



Ranking levels

Our Estimation	Rate
Very High preferred	9
Highly preferred	7
Strongly preferred	5
Slightly preferred	3
Equally preferred	1

- Intermediate values 2, 4, 6 and 8 can be used as additional ranking levels
- In addition, the rule of reversed ranking also applies.
  - If a criterion or a supplier *i* has a particular rate with respect to *j*, then the reversed rate is assumed if *j* is compared against *i*.

Comparison of alternatives

- First, we compare each supplier (in pairs) for each criterion.
- Need to construct an assessment matrix for each pair of criteria.
  - For example, S1 is strongly preferred to S2 with respect to Quality; S4 is lightly preferred to S1, etc.
  - Similarly, with respect to Service, S2 is strongly preferred S1, etc.
  - We do the same for all pairs of suppliers with respect to all criteria.

A. Quality				
	S1	**S2**	**S3**	**S4**
S1	1	5	6	1/3
S2	1/5	1	2	1/6
S3	1/6	1/2	1	1/9
S4	3	6	9	1
Weights	0.297	0.087	0.053	0.563
B. Cost				
S1	1	1/3	5	8
S2	3	1	7	9
S3	1/5	1/7	1	2
S4	1/8	1/9	1/2	1
Weights	0.303	0.573	0.078	0.046
C. Service				
S1	1	5	4	8
S2	1/5	1	1/2	1/3
S3	1/4	2	1	5
S4	1/8	1/4	1/5	1
Weights	0.597	0.140	0.214	0.050
D. Response				
S1	1	3	1/5	1
S2	1/3	1	1/8	1/3
S3	5	8	1	5
S4	1	3	1/5	1
Weights	0.151	0.060	0.638	0.151

Comparison of criteria

- Next, we construct an assessment matrix for each pair of criteria.
  - For example, we first consider that **Quality** is equally and perhaps very slightly preferred compared to **Cost.** In this case, we put 2.
  - Then, we consider that **Cost** is slightly preferred compared to **Service**. In this case we put 3.
  - We do the same for all pairs of criteria. However, be careful and put meaningful values

Criteria preference matrix

A. Initial Matrix

	Quality	Cost	Service	Response
Quality	1	2	4	3
Cost	1/2	1	3	3
Service	1/4	1/3	1	2
Response	1/3	1/3	½	1
Total	25/12	11/3	17/2	9

B. Normalized matrix

	Quality	Cost	Service	Response		Weight
Quality	12/25	6/11	8/17	1/3	=	**0.457**
Cost	6/25	3/11	6/17	1/3	=	**0.300**
Service	3/25	1/11	2/17	2/9	=	**0.138**
Response	4/25	1/11	1/17	1/9	=	**0.105**

The weights are the average values of each row and their sum equals 1

Analytical Hierarchy Process

- In this particular example, the weights for each criterion are 0.457, 0.3, 0.138 and 0.105, respectively.

- On the basis of the above, we can conclude that Quality is 1½ times (0.457/0.300) more important compared to Cost, a little more that 3 times (0.457/0.138) more important compared to Service, and approximately 4 times (0.457/0.105) more important compared to Response.

- And so on…..

Analytical Hierarchy Process

- The final step is to calculate the total weighted multi-score for each supplier for all criteria:

	Quality	Cost	Service	Response		
S1	(0.457)(0.297) +	(0.300)(0.303) +	(0.138)(0.597) +	(0.105)(0.151)	=	0.325
S2	(0.457)(0.087) +	(0.300)(0.573) +	(0.138)(0.140) +	(0.105)(0.060)	=	0.237
S3	(0.457)(0.053) +	(0.300)(0.076) +	(0.138)(0.214) +	(0.105)(0.638)	=	0.144
S4	(0.457)(0.563) +	(0.300)(0.046) +	(0.138)(0.050) +	(0.105)(0.151)	=	0.294
				Total		1.000

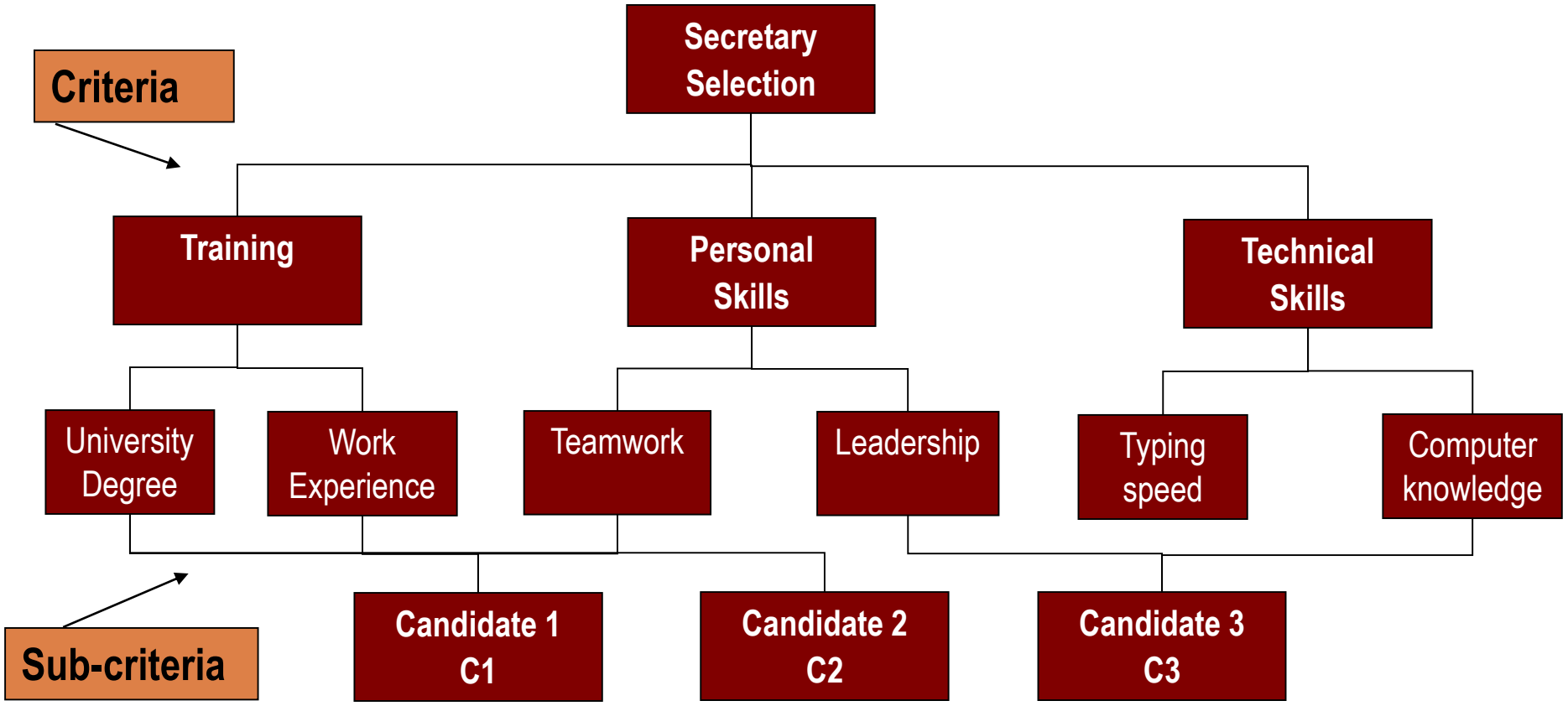
- The final rank of each supplier is the result of the weighted contribution w.r.t all criteria
- In this particular example, suppler S1 (0.325) is the best, and must be selected.

Applications of AHP
in Human Resources Management

Example 1: Personnel Selection

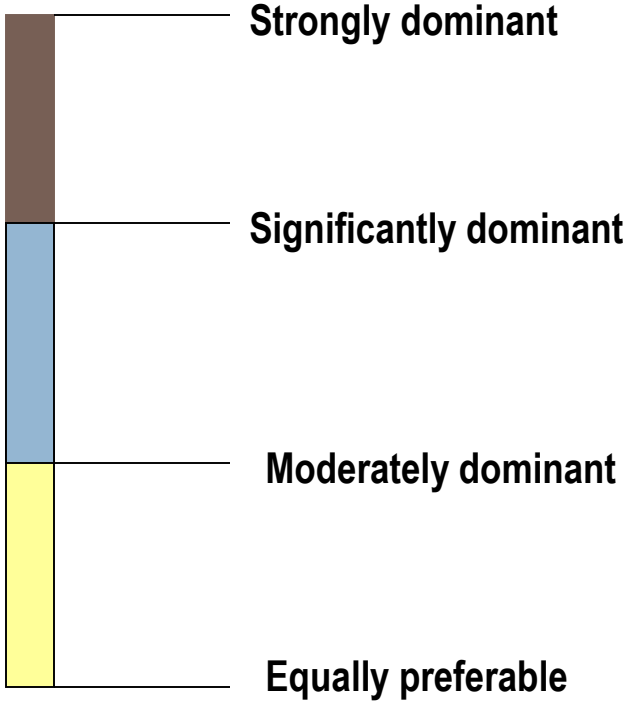
- The HRM department has come up with a short list of candidates that fulfill the criteria for a position
- We want to proceed to a final hierarchy based on basically qualitative criteria

Mapping of the problem



1-by-1 comparison of the candidates for each criterion

Comparison scale



Examples:

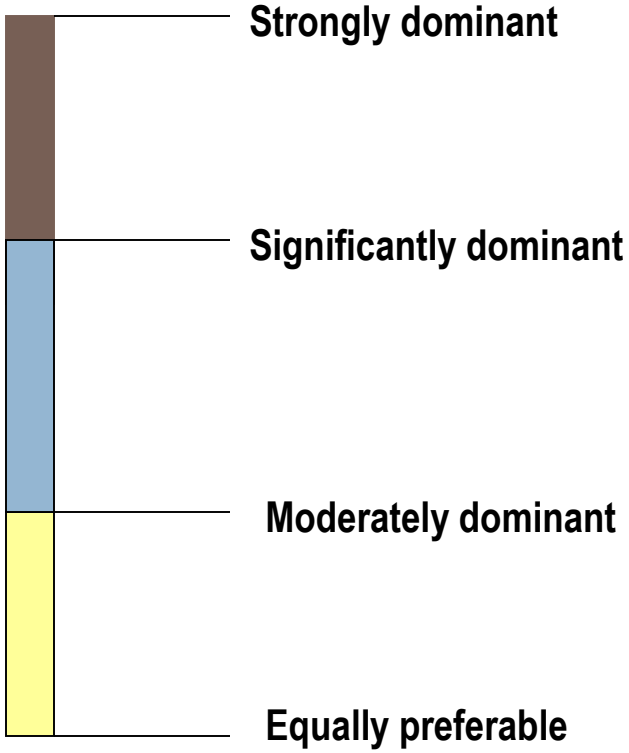
- Candidate C3 is strongly superior to C2 w.r.t to computer knowledge

- Candidate C3 is strongly superior to C1 w.r.t to experience

- Candidate C1 is moderately superior to C2 w.r.t to eagerness

1-by-1 comparison of the criteria

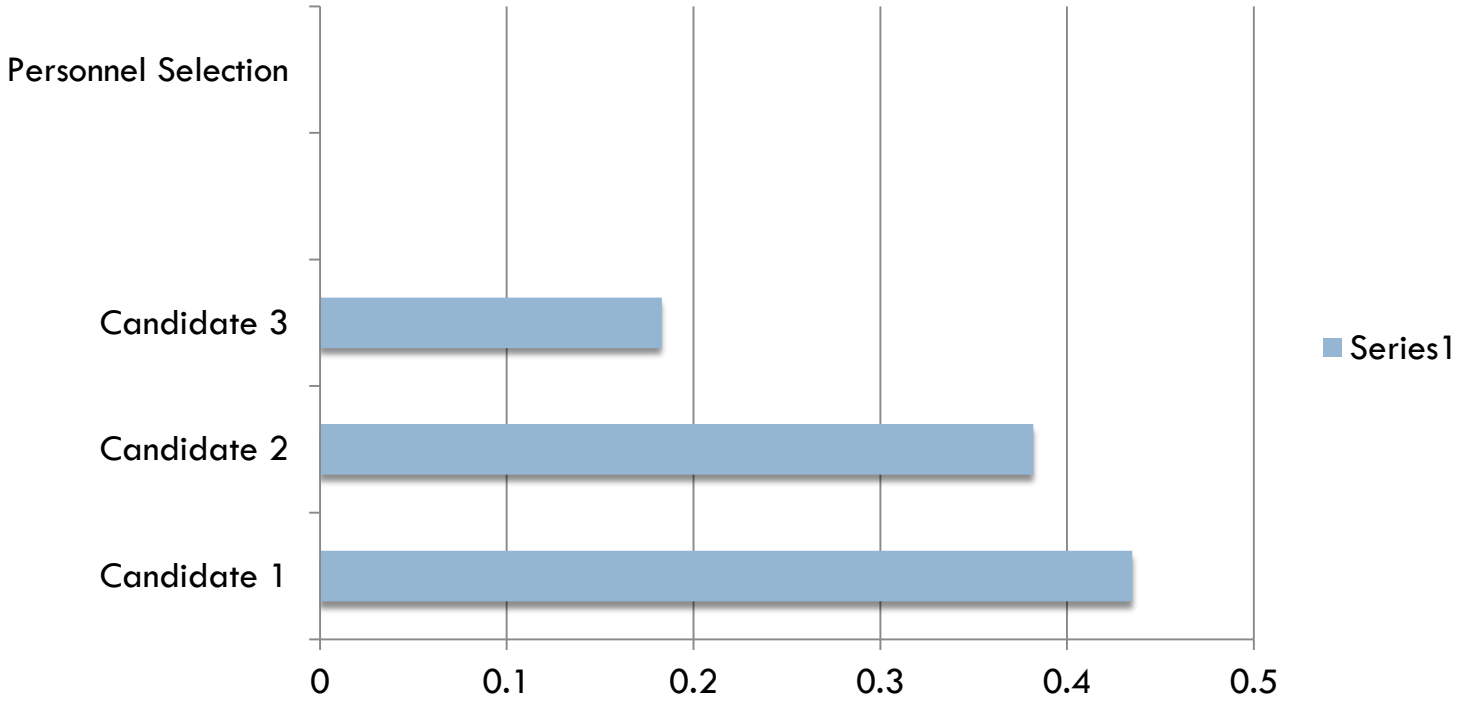
Comparison scale



Examples:

- Education is equally important to education
- Eagerness is moderately more important than appearance
- Computer knowledge is significantly more dominant than stenography

Final recommendation



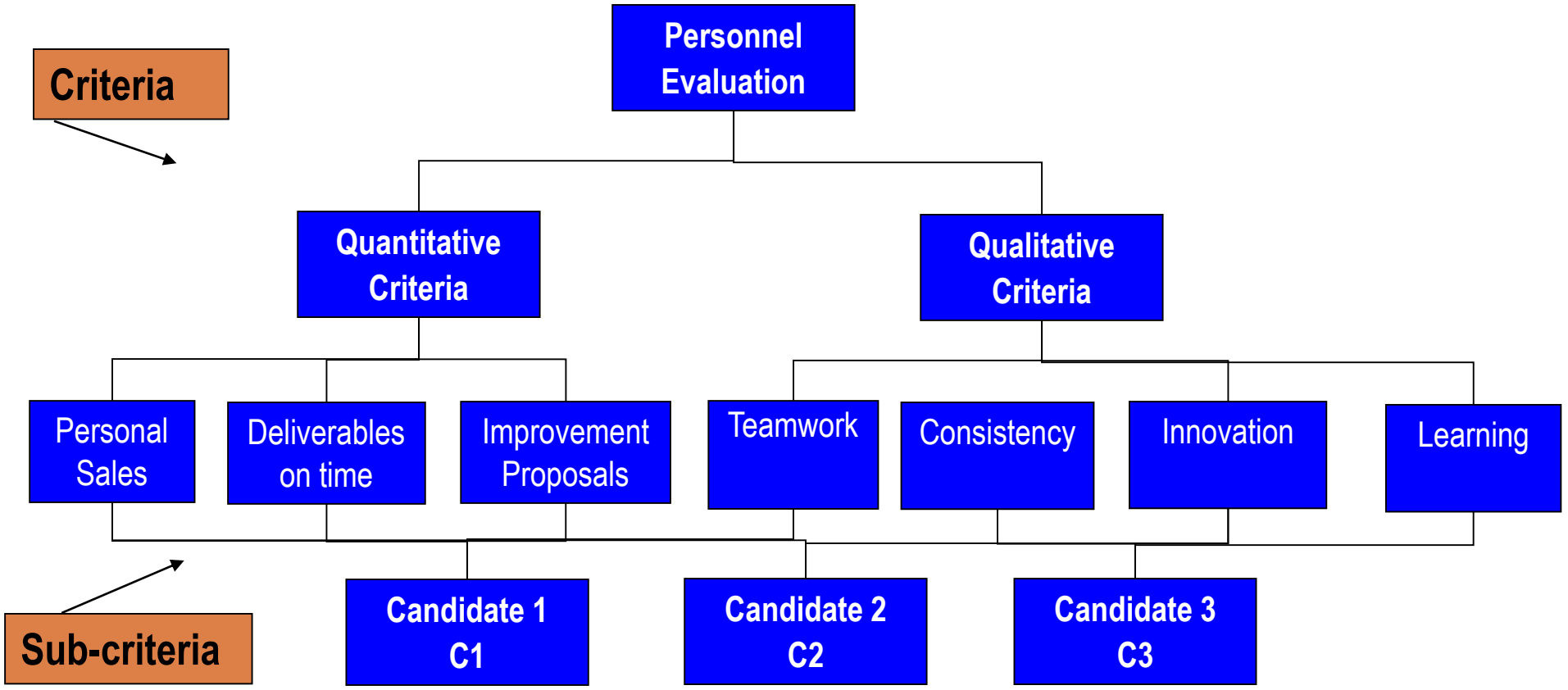
Characteristics of the process

- Objectivity and transparency
- Becoming conscious of the criteria – possibility of changing criteria and possibility of impacting the decision – Sensitivity Analysis
- Basis for discussion

Example 2: Bonus selection

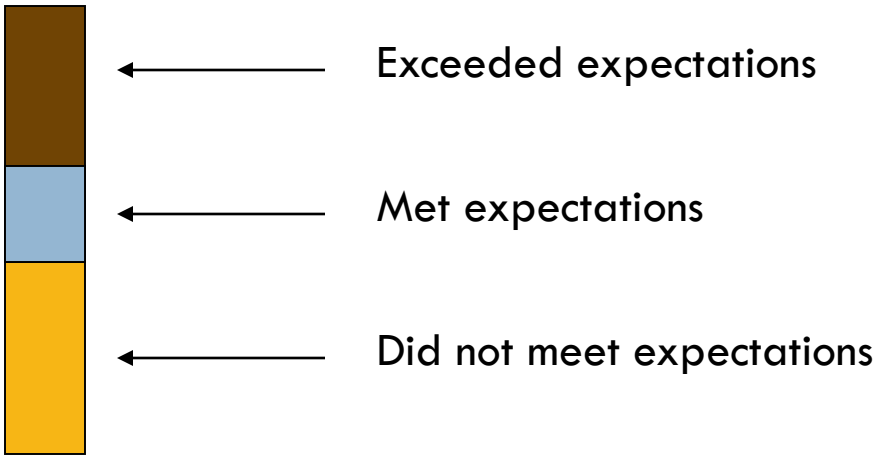
- The company is planning the bonus to be given at the end of the year
- Bonuses will be given according to a merit system
- Consider
  - Quantitative criteria (sales, timetable-on-time, improvement proposals)
  - Qualitative criteria (teamwork, innovation, consistency, learning)

Mapping of the problem



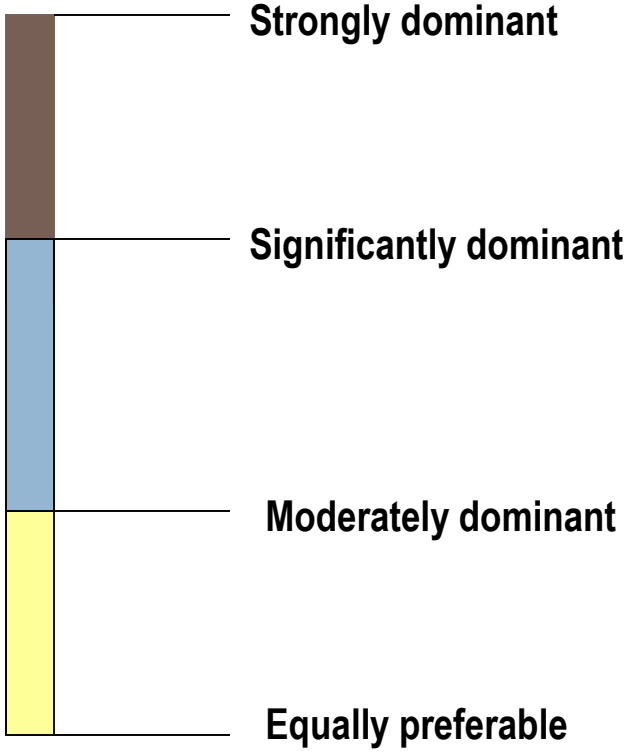
Evaluation scale

- For the quantitative criteria
  - Quantitative measurement (e.g. sales)
- For the qualitative criteria



1-by-1 comparison of the criteria

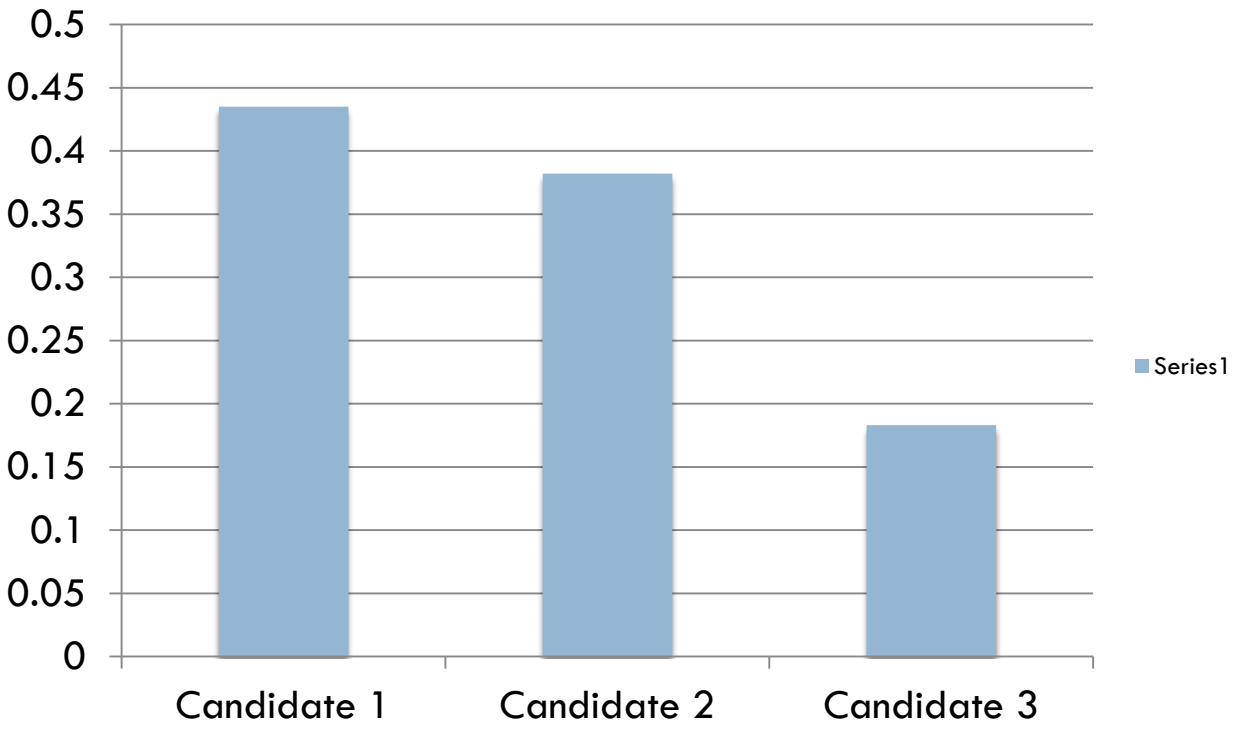
Comparison scale



Examples:

- Teamwork is equally to moderately more important than learning
- Innovation is moderately more important than teamwork
- Innovation is equally to moderately more important than consistency

Final Recommendation



Characteristics of the process

- Proposal to HRM: Bonuses to be given in analogy of the "evaluation points"
- Objectivity and transparency
- Complete documentation of the proposal, and therefore acceptance by the personnel
- We become conscious of the criteria, possibility of conducting sensitivity analysis