

Introduction to SWOT/AHP

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Acknowledgments: I thank Alfred Posch for contributing several slides.

Learning goals

- Refresh your knowledge on standard SWOT analysis
- Conduct a SWOT analysis with cross-category comparison
- Extend SWOT analysis with an Analytical Hierarchy Process (AHP) to prioritize factors

$$w(a)_i/w(b)_i = \begin{cases} a_i > b_i, & w(a)_i/w(b)_i \in \{3/1, 5/1, 7/1, 9/1\} \\ a_i \approx b_i, & w(a)_i/w(b)_i = 1 \\ a_i < b_i, & w(a)_i/w(b)_i \in \{1/3, 1/5, 1/7, 1/9\} \end{cases} \quad (1)$$

$$A = \begin{bmatrix} 1 & \dots & w_a/w_d \\ \vdots & \ddots & \vdots \\ \frac{1}{w_a/w_d} & \dots & 1 \end{bmatrix}$$

$$w_a/w_b = \begin{cases} \sum_{i=1}^n w(a)_i > \sum_{i=1}^n w(b)_i, & \frac{w_a}{w_b} = \frac{\sum_{i=1}^n w(a)_i}{\sum_{i=1}^n w(b)_i} \\ \sum_{i=1}^n w(a)_i = \sum_{i=1}^n w(b)_i, & w_a/w_b = 1 \\ \sum_{i=1}^n w(a)_i < \sum_{i=1}^n w(b)_i, & \frac{w_a}{w_b} = \left(\frac{\sum_{i=1}^n w(b)_i}{\sum_{i=1}^n w(a)_i} \right)^{-1} \end{cases} \quad (2)$$

$$w_b/w_a = \frac{1}{w_a/w_b}$$

$$A \times v = \lambda v$$

$$(A - \lambda_{\max} I) v = 0$$

$$CI = (\lambda_{\max} - n) / (n - 1)$$

$$CR = 100(CI/ACI)$$

SWOT Analysis

- Structured and strategic planning method
- Evaluation of
 - Strengths
 - Weaknesses
 - Opportunities
 - Threats

of a company / project / product / **technology**





All images from commons.wikimedia.org

...a common mistake

- Avoid mixing up external and internal factors, i.e.
 - external opportunities with internal strengths
 - external threats with internal weaknesses

Cross-category analysis (TOWS)

- How may opportunities be capitalized upon in the face of the prevailing strengths (O-S)?
- How may weaknesses be overcome so that the defined opportunities may be actuated (O-W)?
- How may strengths be drawn on in order to reduce vulnerability to threats (T-S)?
- How can an examination of the (T-W) relation aid the formulation of a defense strategy?

Exercise

- Draft a simple SWOT analysis for battery electric vehicles (BEV)
 - Try to think of at least three factors per category
- Conduct a cross-category analysis
 - Perspective: BEV manufacturer
 - O-S, O-W, T-S, T-W
- In a research paper each factor needs to be justified, i.e., based on literature or empirical work
 - This is not necessary for this exercise

BEV SWOT draft

- One strength could be
 - Better environmental performance
- One weakness could be
 - Higher price
- One opportunity could be
 - New developments on the battery sector
- One threat could be
 - Technical challenges for grid infrastructure

ANALYTIC HIERARCHY PROCESS – AHP

AHP Basics

- Developed by Thomas L. Saaty (1926-2017)
- Aim: Support decision making
 - In particular: Group decision making
 - Multi-criteria decision



- Literature




- Saaty, Thomas L. (2006). Fundamentals of Decision Making and Priority Theory. Pittsburgh, Pennsylvania: RWS Publications. ISBN 0-9620317-6-3.
- Saaty, Thomas L. (2008). Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World. Pittsburgh, Pennsylvania: RWS Publications. ISBN 0-9620317-8-X.

AHP example: Find the best candidate!

- Classical Example from Saaty books
 - See also en.wikipedia.org/wiki/Analytic_hierarchy_process_-_leader_example
 - The following slides are based on the Saaty books and the Wikipedia article (as of March 2021)
- Alternative example
 - <https://www.youtube.com/watch?v=18GWVtVAAzs>

Image source: en.wikipedia.org/wiki/File:AHP_TDHBiographies.png

Three candidates

	 Tom	 Dick	 Harry
Age	50 years	60 years	30 years
Experience	10 years with us, plus 16 in a different industry, all in sales and marketing, all with great success. Currently VP Sales, Marketing, and Customer Service.	30 years with us, 8 in another company in our industry. Has had key responsibilities in every department. Currently Executive VP.	5 years with us, 4 with a CPA firm. Completed the management training program in record time and with record performance. Currently VP Finance.
Education	BS, Marketing, Marietta College, 26 years ago. Online MBA, University of Phoenix, last year.	BA and MA, American History, Duke University, 39 years ago. Phi Beta Kappa.	BS, Economics, Princeton, 10 years ago. MBA, Pittsburgh, 5 years ago. Licensed CPA.
Leadership Qualities	An active, inspirational leader. Beloved by his subordinates and all those who have ever worked with him.	A bit reserved. Leads by example and strength of knowledge. Everyone in the company likes him and respects him.	Leads quietly from his office. Highly respected for his brilliance and knowledge of financial matters.

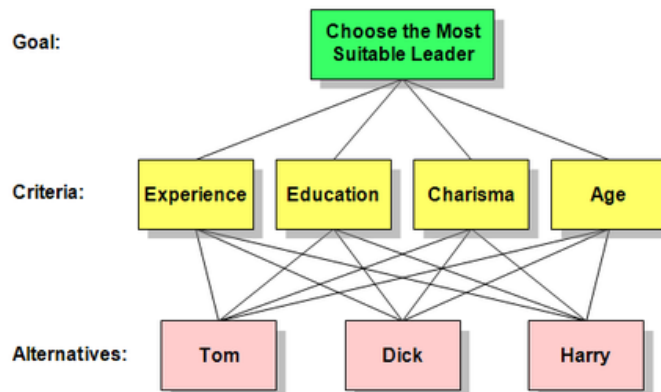
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https://en.wikipedia.org/wiki/File:AHP_TDHHierarchyBasic.png

Decision hierarchy



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en.wikipedia.org/wiki/File:AHPFundamentalScaleModerately.png

Pair-wise comparisons

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment moderately favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities of 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

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Scale

Factor 1 /Factor 2

9/1 ... 7/1 ... 5/1 ... 3/1 ... 1/1 ... 1/3 ... 1/5 ... 1/7 ... 1/9



F1 much more important



F2 much more important

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Scale (2)

Performance of candidates
regarding a certain criterion

9/1 ... 7/1 ... 5/1 ... 3/1 ... 1/1 ... 1/3 ... 1/5 ... 1/7 ... 1/9



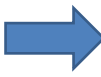
Candidate 1
much better



Candidate 2
much better

Pair-wise comparisons (ctd.)

Tom	1	Dick	4
Tom	4	Harry	1
Dick	9	Harry	1



Experience	Tom	Dick	Harry
Tom	1	1/4	4
Dick	4	1	9
Harry	1/4	1/9	1

Calculating priorities

Experience	Tom	Dick	Harry	Priority
Tom	1	1/4	4	0.217
Dick	4	1	9	0.717
Harry	1/4	1/9	1	0.066
Sum of Priorities				1.000
Inconsistency				0.035

➤ AHP calculates relative priorities

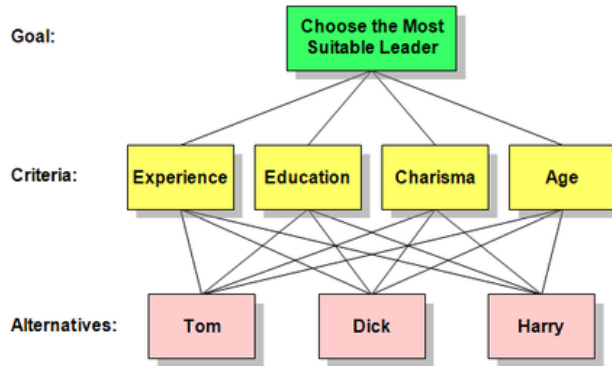
- Based on the judgment of decision makers
- Priorities = matrix's principal right eigenvector
- Consistency index (aka inconsistency factor) from eigenvalue

Sources:

- Kurttila M., Pesonen M, Kangas J. & Kajanus M. (200). Utilizing the analytic hierarchy process (AHP) in SWOT analysis—a hybrid method and its application to a forest-certification case. *For. Policy Econ.*, 41-52
- Posch A, Brudermann T, Braschel N & Gabriel M. (2015). Strategic energy management in energy-intensive enterprises – a quantitative analysis of relevant factors in the Austrian paper and pulp industry. *Journal of Cleaner Production* 90:291-299.
- Brudermann T & Sangkakool T (2017). Green roofs in temperate climate cities in Europe – an analysis of key decision factors. *Urban Forestry and Urban Greening* 21:224-234.

AHP IN SWOT ANALYSIS

Classical AHP Hierarchy vs. ...

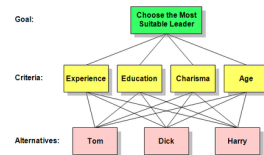


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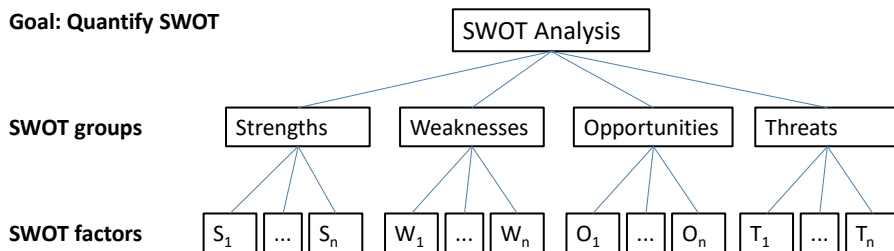
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...SWOT Hierarchy



Goal: Quantify SWOT



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SWOT/AHP in four steps

1. SWOT analysis
2. Respondents' judgments
 - Pair-wise comparison of factors within every SWOT group
 - Pair-wise comparison of the four SWOT groups (Alternative: Compare most important factor of each group)
3. AHP Calculation
 - Local factor priority (relative to other group factors)
 - Global factor priority (local priority weighted by group priority)
4. Strategy formulation

Judgments (pair-wise comparisons*)

**Note: In this example, even numbers (intermediate steps) have been left out.*

Possible strengths of the Austrian pulp and paper industry

Which of the following strengths is in your opinion more important resp. how much more important for the pulp and paper industry in Austria?

Please select the applicable answer for each comparison:

	Much more important			Equally important			Much more important			
Energy efficiency of production processes	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Availability of co-generation on-site
Flexibility in changing energy carrier	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Strategic collaboration with energy suppliers

Expert judgments (ctd.)

When comparing the strengths with the weaknesses, which of them have more importance for the branch in general, respectively how much more importance?

Please select the applicable answer for each comparison:

Much more important Equally important Much more important
 Strengths ○ ○ ○ ○ ○ ○ ○ ○ ○ Weaknesses

Strengths	Weaknesses
Energy efficiency of production processes	Dependency on energy market and energy prices
Possibility of the own co-generation of electricity and heat	Inefficiency through excess of thermal energy
Flexibility in changing energy carrier	Energy efficiency depends on capacity utilization
Strategic collaboration with energy suppliers	Limited ability to generate renewable energy

Posch A, Bruderermann T, Braschel N & Gabriel M. (2015). Strategic energy management in energy-intensive enterprises – a quantitative analysis of relevant factors in the Austrian paper and pulp industry. *Journal of Cleaner Production* 90:291-299. 25

Aggregation of judgments

Expert	S : W	S : O	S : T	W : O	W : T	O : T
#1	8 : 1	1 : 1	3 : 1	9 : 1	1 : 1	5 : 1
#2	7 : 1	5 : 1	1 : 1	1 : 7	1 : 1	7 : 1
#3	5 : 1	6 : 1	4 : 1	1 : 7	1 : 4	3 : 1
#4	4 : 1	1 : 5	6 : 1	1 : 2	1 : 8	2 : 1
#5	6 : 1	1 : 9	1 : 8	1 : 2	1 : 7	1 : 1
#6	5 : 1	1 : 9	1 : 5	1 : 6	1 : 2	2 : 1
#7	1 : 5	1 : 5	1 : 3	1 : 3	1 : 7	1 : 9
Mean*	4.4 : 1.3	1.6 : 3.0	...			

***Note:** it is suggested to use the **geometric mean** to aggregate the individual judgments.

Example: Comparison of 3 factors

$S_1 : S_2$	$S_1 : S_3$	$S_2 : S_3$
1 : 3	5 : 1	7 : 1

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Pair-wise comparison

$S_1 : S_2$	$S_1 : S_3$	$S_2 : S_3$
1 : 3	5 : 1	7 : 1

	S1	S2	S3
S1	1/1	1/3	5/1
S2		1/1	7/1
S3			1/1

S2 is moderately more important than S1 (3:1)

S2 is strongly more important than S3 (7:1)

1/1 indicates equal importance
9/1 indicates extreme relative importance

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Pair-wise comparison

$$\begin{array}{ccc} S_1 : S_2 & S_1 : S_3 & S_2 : S_3 \\ 1 : 3 & 5 : 1 & 7 : 1 \end{array}$$

$$A = \begin{bmatrix} 1 & \cdots & w_a/w_d \\ \vdots & \ddots & \vdots \\ \frac{1}{w_a/w_d} & \cdots & 1 \end{bmatrix}$$

	S1	S2	S3
S1	1/1	1/3	5/1
S2	3/1	1/1	7/1
S3	1/5	1/7	1/1

1/1 indicates equal importance

9/1 indicates extreme relative importance

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Eigenvalue technique

1. Calculate the eigenvector of the resulting matrix.
2. Multiply the matrix by itself.
3. Calculate the eigenvector by summing up the rows and normalizing the sums.
4. Repeat steps 1 and 2 until the difference to the newly calculated eigenvector is minimal.

Matrix multiplication

$$\mathbf{A} = \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{pmatrix}, \quad \mathbf{B} = \begin{pmatrix} B_{11} & B_{12} & \cdots & B_{1p} \\ B_{21} & B_{22} & \cdots & B_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ B_{m1} & B_{m2} & \cdots & B_{mp} \end{pmatrix}$$

the **matrix product** \mathbf{AB} (denoted without multiplication signs or dots) is defined to be the $n \times p$ matrix^{[3][4][5][6]}

$$\mathbf{AB} = \begin{pmatrix} (\mathbf{AB})_{11} & (\mathbf{AB})_{12} & \cdots & (\mathbf{AB})_{1p} \\ (\mathbf{AB})_{21} & (\mathbf{AB})_{22} & \cdots & (\mathbf{AB})_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ (\mathbf{AB})_{n1} & (\mathbf{AB})_{n2} & \cdots & (\mathbf{AB})_{np} \end{pmatrix}$$

where each i, j entry is given by multiplying the entries A_{ik} (across row i of \mathbf{A}) by the entries B_{kj} (down column j of \mathbf{B}), for $k = 1, 2, \dots, m$, and summing the results over k :

$$(\mathbf{AB})_{ij} = \sum_{k=1}^m A_{ik} B_{kj}.$$

Source: Wikipedia

Matrix multiplication

- In Excel, you may just use the matrix multiplication function MMULT
 - (see Office support sites for details)

Consistency Index / Consistency Ratio

$$CI = (\lambda_{\max} - n) / (n - 1)$$

$$CR = CI / ACI$$

Consistency Index

Step 1: Multiply matrix with its Eigenvector

	S1	S2	S3		Eigenvector	Multi-result
S1	1,00	0,50	3,00		0,29	0,73
S2	2,00	1,00	4,00	*	0,43	1,71
S3	0,33	0,25	1,00		0,06	0,18

$$CI = (\lambda_{\max} - n) / (n - 1)$$

$$CR = CI / ACI$$

Consistency Index

Step 2: The mean of Eigenvalues becomes your λ_{\max}

Multi-result	Eigenvector	Eigenvalue
0,73 /	0,29 =	2,57
1,71 /	0,43 =	4,00
0,18 /	0,06 =	2,93
mean		
3,17 = estimate for λ_{\max}		
$\lambda_{\max} \geq n$		

$$CI = (\lambda_{\max} - n) / (n - 1)$$

$$CR = CI / ACI$$

Consistency Index

Step 3: Calculate CI according to the formula

$$CI = (\lambda_{\max} - n) / (n-1)$$

$$CI = (3,17-3)/2 = 0,084$$

Consistency Ratio

Step 4: Calculate CR

Average consistency index (ACI) based on random judgements depending on order of matrix:

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,48	1,56	1,57	1,59

(Saaty 1980)

$$CR = CI/ACI = 0,084 / 0,58 = 0,145$$

CR should be < 0.1 according to Saaty

AHP CALCULATIONS IN EXCEL

Strategy development

- SWOT with cross-category comparisons provides a firm basis
- AHP provides a quantitative extension

Limitations of the method

- Sampling strategy affects results
- Practically, only limited number of SWOT factors can be considered
 - Number of comparisons on manageable level
 - Selection of SWOT factors for AHP
- Potential bias
 - Same number of factors per category?
 - Different number of factors per category?
- ...

Assignment

- Draft a SWOT analysis on BEVs
 - For this exercise it is ok to base it on your own perceptions
 - Three factors per group
- Apply AHP method to your SWOT analysis
 - Do all the necessary pairwise comparisons
 - Enter your comparisons into an excel file
 - Calculate priorities based on this presentation.

Thanks for your attention.