MOBILITY, LOGISTICS & AUTOMOTIVE TECHNOLOGY RESEARCH CENTRE

A CRITERIA PRE-PROCESSING FRAMEWORK

IN THE MULTI-ACTOR MULTI-CRITERIA ANALYSIS

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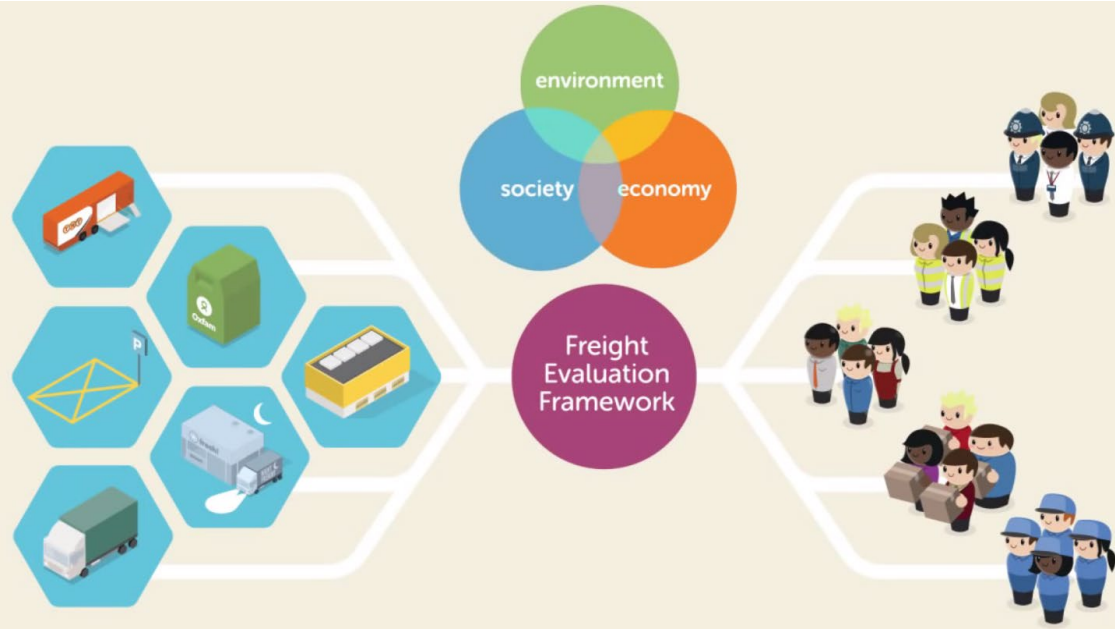
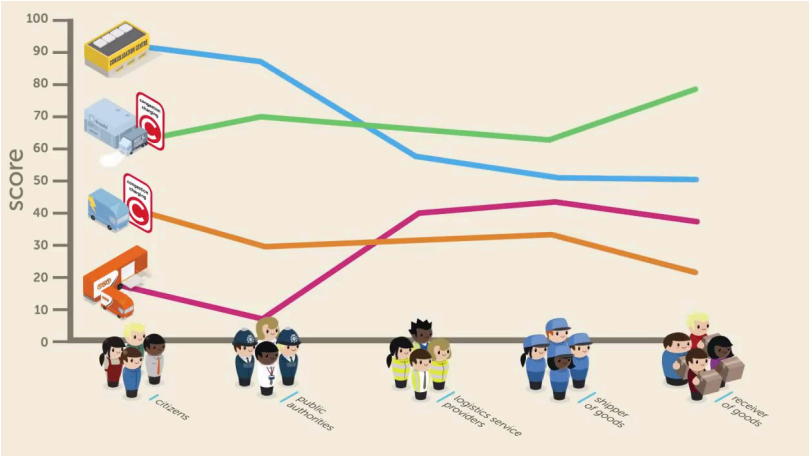
THE DISTINCTION OF MAMCA

MULTI-ACTOR MULTI-CRITERIA ANALYSIS

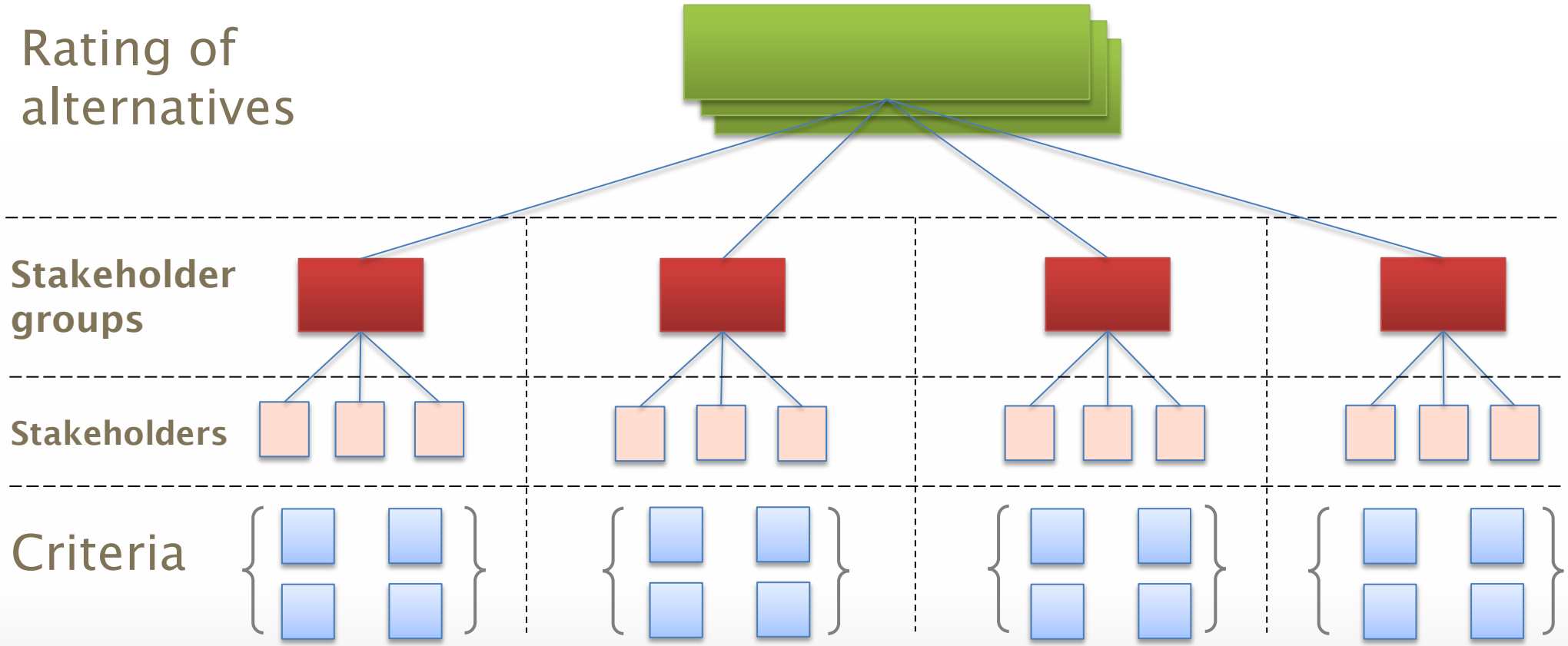


A multi-criteria group decision making (MCGDM) framework which allows for the inclusion of multiple stakeholders.



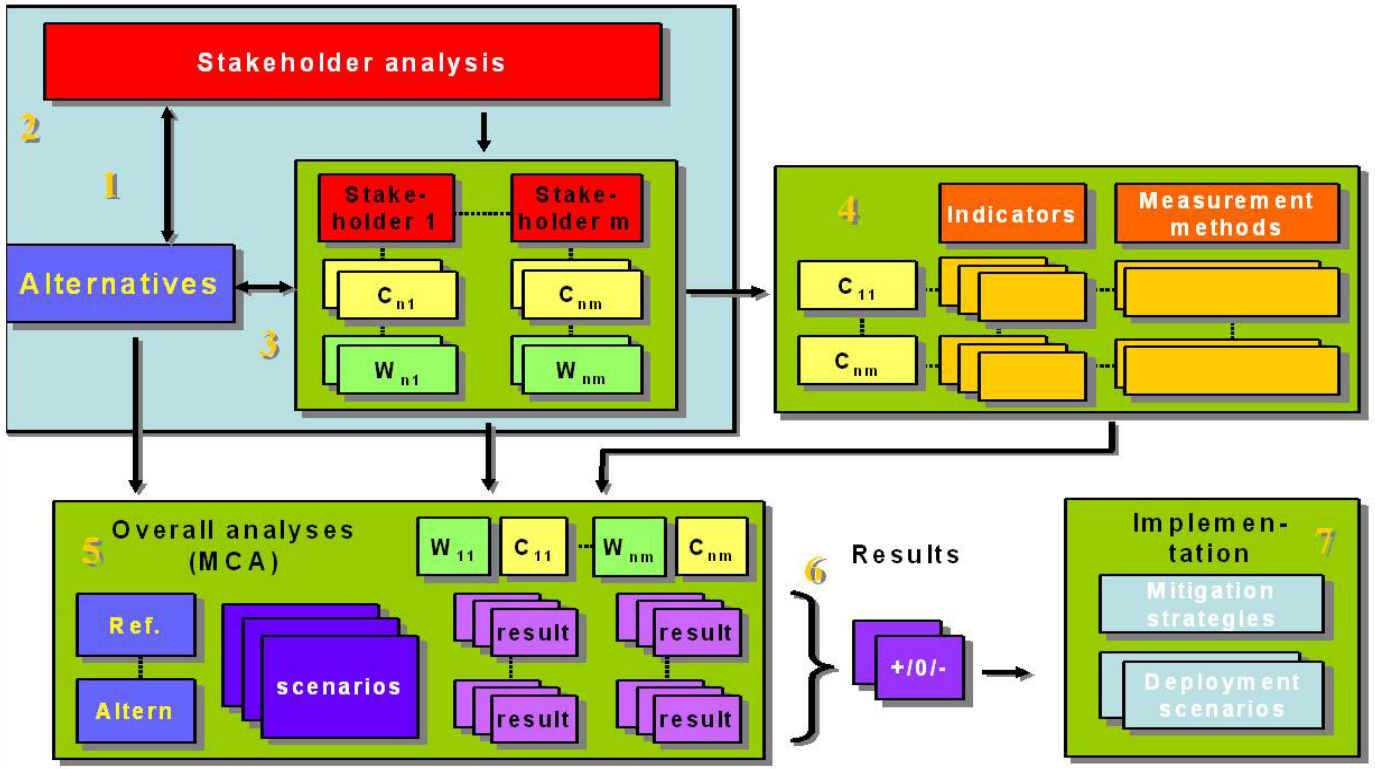
THE DISTINCTION OF MAMCA

STRUCTURE OF THE MAMCA



MAMCA METHODOLOGY

FRAMEWORK

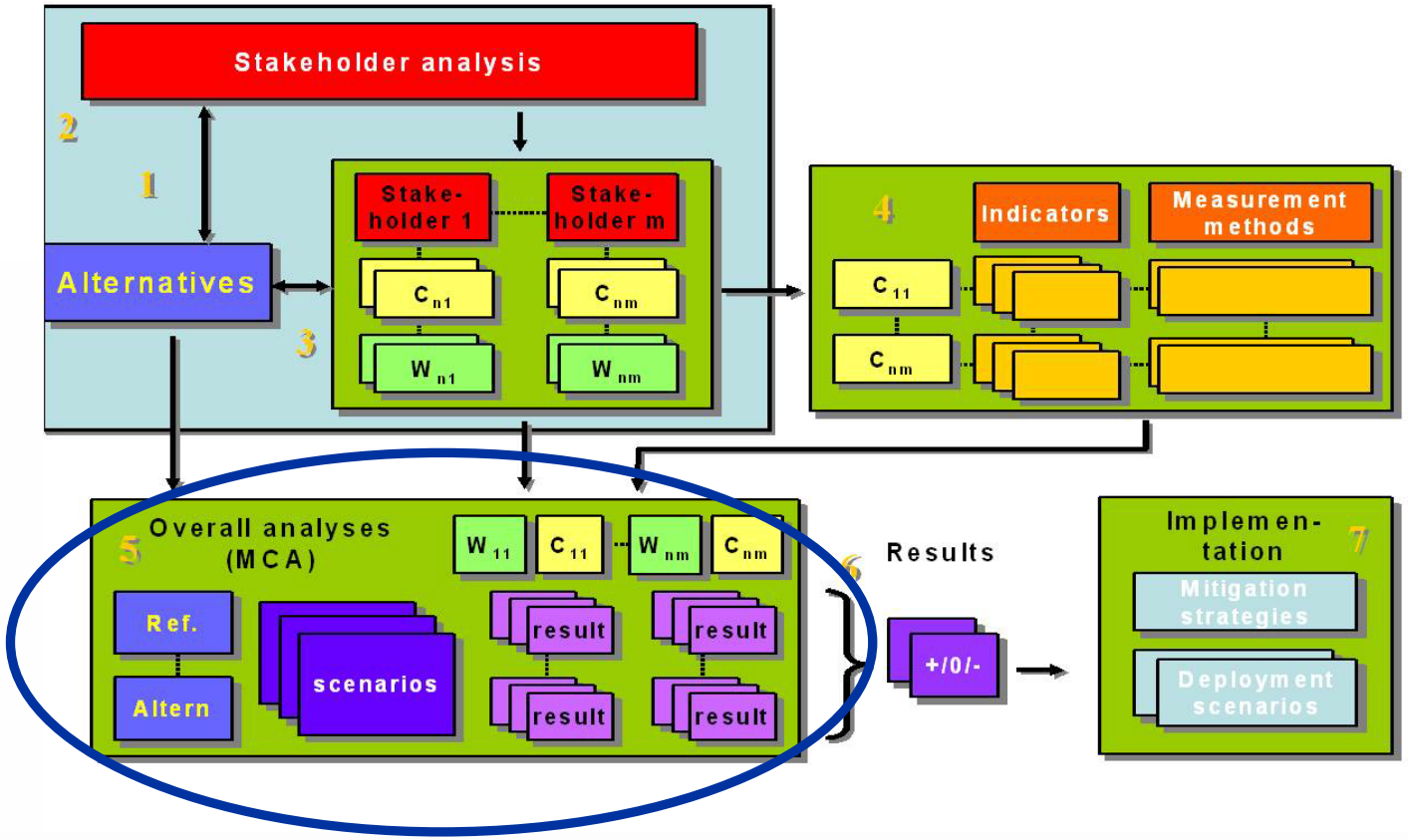


1	Define alternatives
2	Stakeholder analysis
3	Define criteria and weights
4	Criteria, indicators and measurement methods
5	Overall analysis and ranking
6	Result
7	Implementation

Macharis, C., Turcksin, L., & Lebeau, K. (2012). Multi actor multi criteria analysis (MAMCA) as a tool to support sustainable decisions: State of use. Decision Support Systems, 54(1), 610-620.

MAMCA METHODOLOGY

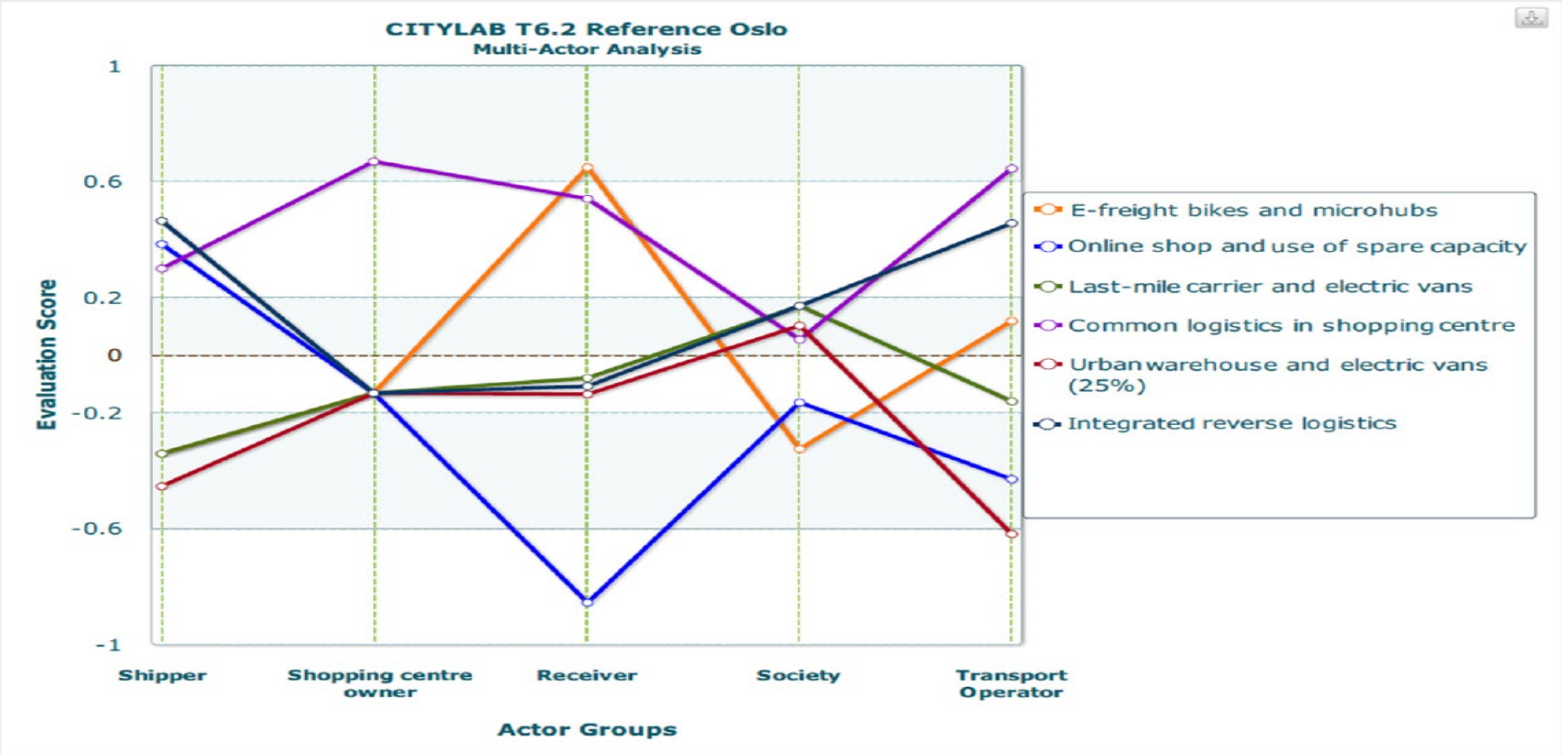
MCDM METHODS



- AHP
- PROMETHEE
- ELECTRE
- ...

MAMCA METHODOLOGY

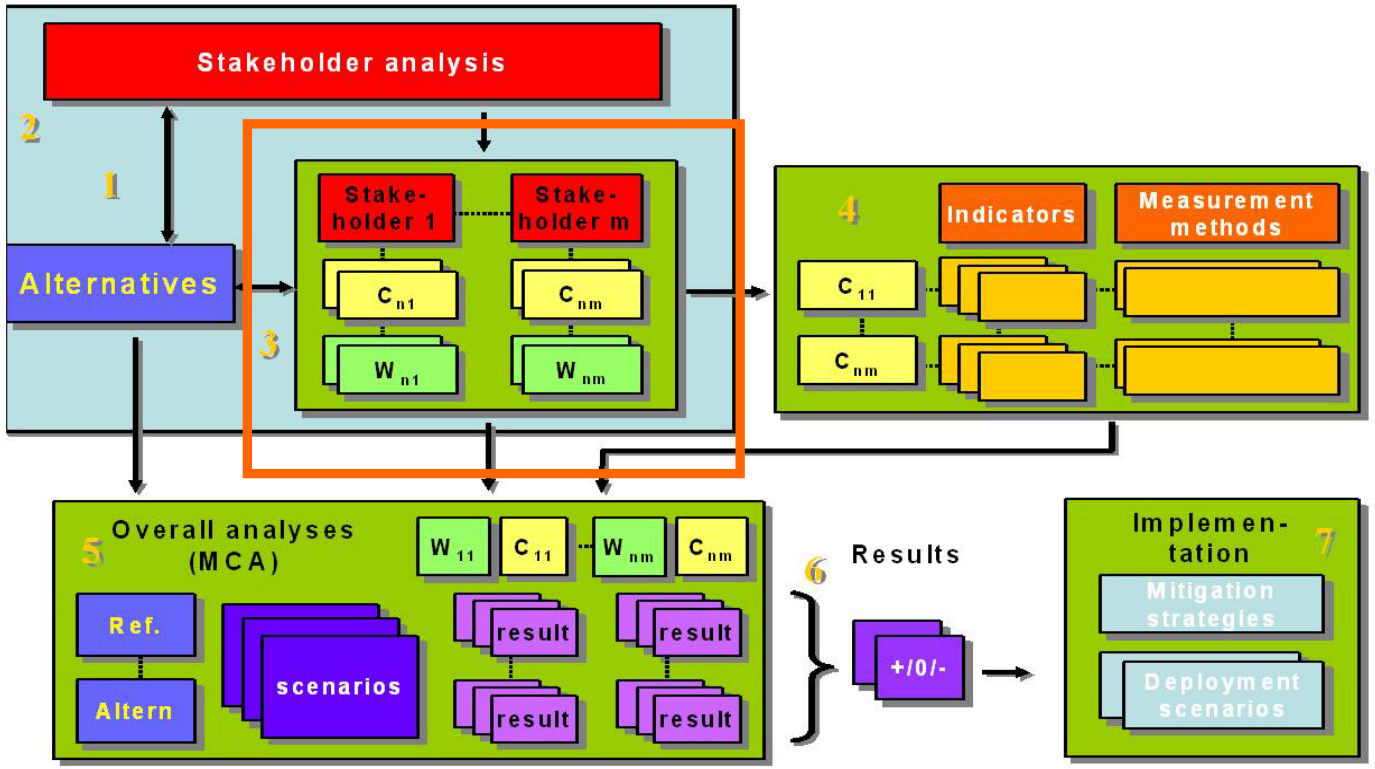
MULTI-ACTOR VIEW



Huang, H., De Smet, Y., Macharis, C., & Doan, N. A. V. (2021). Collaborative decision-making in sustainable mobility: identifying possible consensuses in the multi-actor multi-criteria analysis based on inverse mixed-integer linear optimization. International Journal of Sustainable Development & World Ecology, 28(1), 64-74.

MAMCA METHODOLOGY

FRAMEWORK



1	Define alternatives
2	Stakeholder analysis
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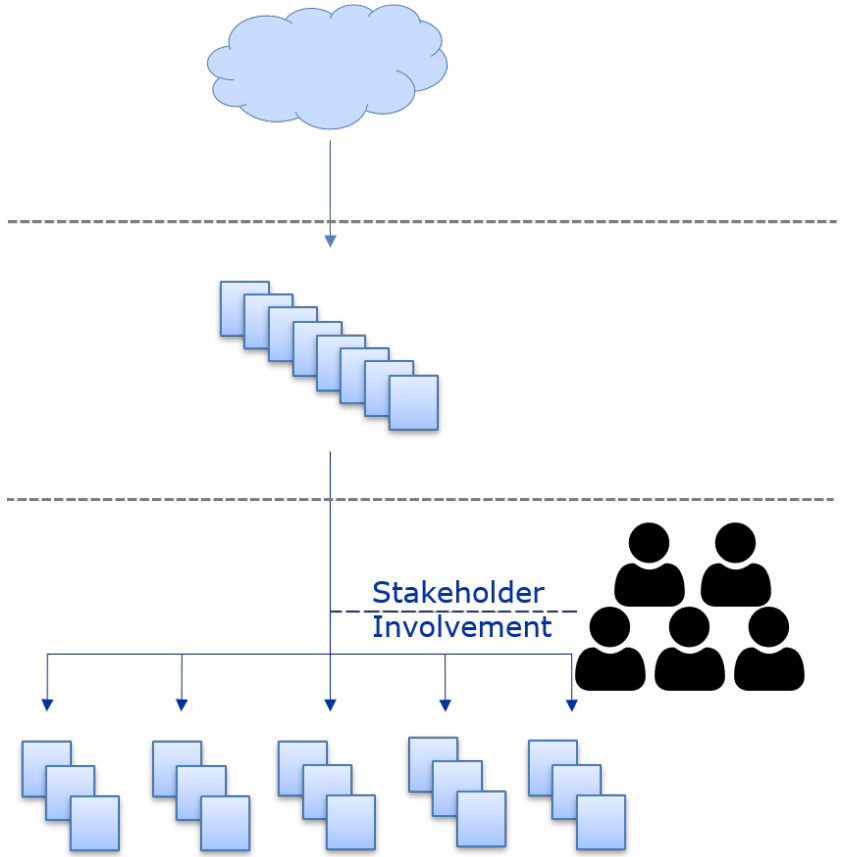
MAMCA METHODOLOGY

CRITERIA PRE-PROCESSING

1. Criteria initial selection
2. Criteria filtering
3. Criteria final selection



Dodgson, J. S., Spackman, M., Pearman, A., & Phillips, L. D. (2009). Multi-criteria analysis: a manual.

CRITERIA PRE-PROCESSING

CRITERIA FINAL SELECTION WITH STAKEHOLDER INVOLVEMENT

For each stakeholder group:

- Members select the relevant criteria
- Select the criteria that most of members think relevant

$$C \coloneqq \{c_1, c_2, \dots, c_n\} \qquad A \coloneqq \{a_1, a_2, \dots, a_m\}$$

$$S_{n\times m} \coloneqq \begin{bmatrix} s_{1,1} & \cdots & s_{1,m} \\ \vdots & \ddots & \vdots \\ s_{n,1} & \cdots & s_{n,m} \end{bmatrix}, s_{i,j} \in \{0,1\} \qquad R \coloneqq \{r_i = \sum_{j=1}^{m} s_{i,j}\,, j \in [1,m]\}$$

$$L = argmax(R' \subset R, |R'| = z)$$

CRITERIA PRE-PROCESSING

LIMITATION

- The intensity of the relevance is not shown
- The heterogeneity of the group is not shown
- Implicit unfairness

NOVEL CRITERIA SELECTION MODEL

RAW DATA

For each stakeholder group:

- Stakeholders select β relevant criteria to them ($\beta \in [5..9]$ →Miller's magic number)
- Give scores to the criteria based on relevant level in a $[1..x]$ Likert scale, for one stakeholder, at least one criterion must be given x

$$S'_{n\times m} := \begin{bmatrix} s'_{1,1} & \cdots & s'_{1,m} \\ \vdots & \ddots & \vdots \\ s'_{n,1} & \cdots & s'_{n,m} \end{bmatrix}, s_{i,j} \in [0..x]$$

Saaty, T. L., & Ozdemir, M. S. (2003). Why the magic number seven plus or minus two. Mathematical and computer modelling, 38(3-4), 233-244.

NOVEL CRITERIA SELECTION MODEL

COLUMN OPERATION: NORMALIZATION FOR INDIVIDUALS

$$S'_{n\times m} := \begin{bmatrix} s'_{1,1} & \cdots & s'_{1,m} \\ \vdots & \ddots & \vdots \\ s'_{n,1} & \cdots & s'_{n,m} \end{bmatrix}, s_{i,j} \in [0..x]$$

$$\begin{array}{c} \\ c_1 \\ c_2 \\ c_3 \end{array} \begin{array}{c} \begin{array}{ccc} a_1 & a_2 & a_3 \end{array} \\ \begin{bmatrix} 5 & 3 & 3 \\ 5 & 4 & 2 \\ 5 & 5 & 5 \end{bmatrix} \end{array}$$

$$\begin{array}{c} \\ c_1 \\ c_2 \\ c_3 \end{array} \begin{array}{c} \begin{array}{ccc} a_1 & a_2 & a_3 \end{array} \\ \begin{bmatrix} 5 & 3 & 3 \\ 5 & 4 & 2 \\ 5 & 5 & 5 \end{bmatrix} \end{array} \Longrightarrow$$ A higher weighting (power) for stakeholder a_1

Normalize columns of matrix:

$$\begin{bmatrix} 5 & 3 & 3 \\ 5 & 4 & 2 \\ 5 & 5 & 5 \end{bmatrix} \quad p_{col} = \frac{\sum_{j=1}^{n} s_{norm}}{n} \Longrightarrow \begin{bmatrix} 0.33 & 0.25 & 0.3 \\ 0.33 & 0.33 & 0.2 \\ 0.33 & 0.42 & 0.5 \end{bmatrix}$$

NOVEL CRITERIA SELECTION MODEL

ROW OPERATION: CONSIDER VARIANCE OF CRITERIA SCORE

$$\begin{matrix} & a_1 & a_2 & a_3 \\ c_1 \\ c_2 \\ c_3 \end{matrix} \begin{bmatrix} 5 & 3 & 3 \\ 5 & 4 & 2 \\ 5 & 5 & 5 \end{bmatrix} \xrightarrow{\text{row mean}} \begin{bmatrix} 3.67 \\ 3.67 \\ 5 \end{bmatrix} \xrightarrow{\text{variance}}$$

For c_1 and c_2 : c_1 has better mutual consent than c_2

Profile distribution matrix:

$$D := \begin{matrix} & 1 & 2 & 3 & 4 & 5 \\ c_1 \\ c_2 \\ c_3 \end{matrix} \begin{bmatrix} 0 & 0 & 66.7\% & 0 & 33.3\% \\ 0 & 33.3\% & 0 & 33.3\% & 33.3\% \\ 0 & 0 & 0 & 0 & 100\% \end{bmatrix}$$

$$\bar{v}_i = \sum_{k=1}^{5} k \times d_{k,i}$$

$$\sigma_i^2 = \sum_{k=1}^{5} d_{k,i} \cdot (\bar{v}_i - k)^2$$

$$p_{row} = \bar{v} - \sigma \Rightarrow \begin{bmatrix} 2.78 \\ 2.55 \\ 5 \end{bmatrix}$$

Kunsch, P. L., & Ishizaka, A. (2018). Multiple-criteria performance ranking based on profile distributions: An application to university research evaluations. Mathematics and Computers in Simulation, 154, 48-64.

NOVEL CRITERIA SELECTION MODEL

COMBINE BOTH OPERATIONS

Step 1. Column-wise normalization

$S' \rightarrow S''$

Step 2. Rescaling

$S''_{*,m}$ in different scale $\xrightarrow{\text{flatten}}$ $o_{\beta \cdot m} = \left[\min_{S''\backslash 0} s'', \ldots, \max_{S''} s''\right]$

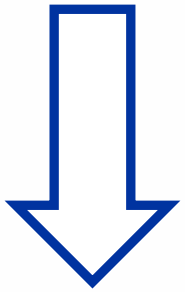
- Consider the probability density and distribution, choose a suitable interval, to put the scores in a same scale
- Generate a new profile distribution matrix based on new scale D'
- Performance score on D': $p' = \sum_{k=1}^{x} k \times d'_k - \sqrt{\sum_{k=1}^{x} d'_k \cdot (\sum_{k=1}^{x} k \times d'_k - k)^2} = \bar{v}' - \sigma'$

NOVEL CRITERIA SELECTION MODEL

CONSIDER 0

Step 3. Processing of 0

- 0 and $[1..x]$ are chosen in different steps, should not be treated together with $[1..x]$
- 0 has fixed number $(n-\beta)\cdot m$ but is distributed on different criteria



- A new indicator for 0 ⟹ Non-zero rate $\gamma_i = 1 - \frac{|\{s'_i=0\}|}{m}$

NOVEL CRITERIA SELECTION MODEL

FINAL PERFORMANCE SCORE

Step 4. Final performance score calculation considering γ_i and D'

$$p_i = (1 - \frac{|\{s'_i = 0\}|}{m}) \cdot \left(\sum_{k=1}^{x} k \times d'_{k,i} - \sqrt{\sum_{k=1}^{x} d'_{k,i} \cdot \left(\sum_{k=1}^{x} k \times d'_{k,i} - k \right)^2} \right)$$

$$= \gamma_i \cdot (\overline{v'_i} - \sigma'_i)$$

$$= \gamma_i \cdot p'_i$$

NOVEL CRITERIA SELECTION MODEL

PARETO ANALYSIS

Step 4. Reorder criteria set $\{c_{\bar{1}}, \dots, c_n,\}$, where $\{p_{\bar{1}} > \cdots > p_{\bar{n}}\}$

- Determine the minimal subset by solving the following optimization problem. The minimal number ($\bar{y}$) of criteria will be found so that their summed aggregate scores will be at least take up α of the total score:

$$\min \bar{y}$$

s.t.

$$\sum_{i=\bar{1}}^{\bar{y}} p_{\bar{\imath}} \geq \alpha \cdot \sum_{i=\bar{1}}^{\bar{n}} p_{\bar{\imath}}$$

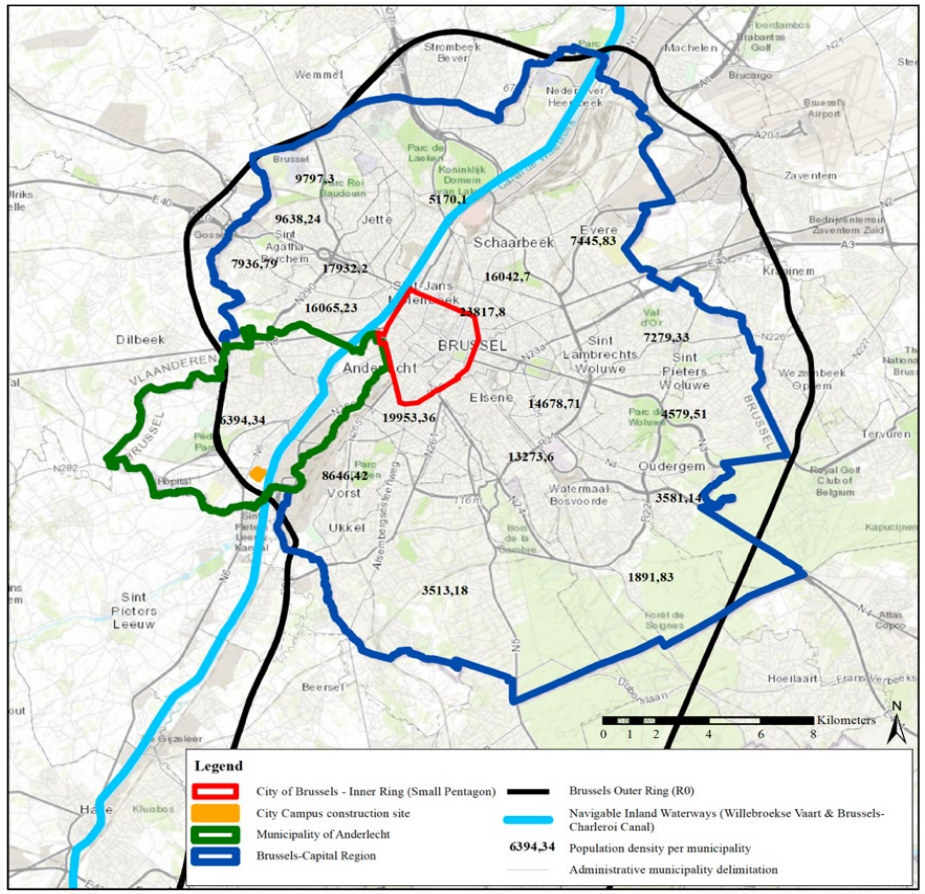
- Set $\alpha = 50\%$ to satisfy majority rules. This should result to $5 \leq \bar{y} \leq 9$. Otherwise, increase the value of α until $\bar{y} = 5$ is obtained. We say that the criteria in the resulting set $\{C_{\bar{1}}, C_{\bar{2}\dots}, C_{\bar{y}}\}$ belong in the ***Definitive Zone***.

- If $\bar{y}$ obtained in Step 1 is equal to 9, stop. Otherwise, further increase α until $\bar{y} = 9$. We say that these additional criteria, i.e., those that are not already in the Definitive Zone, belong in the ***Flexible Zone***.

Azrieli, Y., & Kim, S. (2014). Pareto efficiency and weighted majority rules. International Economic Review, 55(4), 1067-1088

CASE STUDY

CONSTRUCTION LOGISTICS PROJECT



CASE STUDY

CRITERIA INITIAL SELECTION

CRITERIA LIST		
Group	Criterion	Explanation
ECONOMIC CRITERIA	Enforcement costs	Costs to ensure other parties comply with rules in the transport system and/or legislation during the construction works
	Viability of investment	Positive return on investment. For example, the investment in mobility or safety measures should result in more (efficient) work in the long term
	Profitable operations	Objective to generate a profit by providing logistic or transport services during the construction works
	Transportation costs	The costs of transporting construction materials and/or personnel during the project
	Adaptation costs	Financial costs due to mobility impacts caused by the construction site (for example, detours, parking)
	Impact of construction works on transport infrastructure use	Impact of infrastructure works on the efficiency of a transport system, in terms of average speed level, congestion and connectivity and the impact on parking
	Quality and reliability of deliveries of construction materials	The punctuality and the percentage of damage-free delivery of goods (from shipper and recipient perspective)
ENVIRONMENTAL CRITERIA	Air pollution	Impact of construction works on local air quality. The main air pollutants considered in urban areas are sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter (PM2.5 and PM10)
	Climate change	Impact of construction works on greenhouse gas emissions CO2 (global impact)
	Noise pollution	Sound level caused by human activities, including transport, during construction projects
	Vibration	Impact of vibrations during construction works on the surrounding built-up environment, which can cause significant damage
	Water pollution	Impact of construction projects on water quality since construction may pollute water flows and affect volume and velocity
	Biodiversity	Impact of construction works on an area of nature in the vicinity
	Landscape quality	Visual nuisance on surrounding environment
SOCIETAL CRITERIA	Labour conditions	Labour conditions for employees during construction works
	Social and political acceptance by citizens of impacts generated	Level of ease for stakeholders to comply with the authorities' rules and regulations during construction works
	Business climate during construction works	Attractiveness of the area in terms of business opportunities
	Attractiveness (societal)	Impact of construction works on the attractiveness of the urban environment, defined as the recreational facilities in and around the construction zone
	Social and economic revitalisation	Impact after finishing the construction site
	Security of construction material goods during construction works	Probability of construction materials being lost or stolen while being transported to, or stored on, the construction site
	Traffic safety impacts	Traffic accidents during transport of goods and people to, from and within the site, as well as accidents caused by the changes in transport infrastructure at the site
	Accessibility	Accessibility of region in vicinity of construction site by road, public transport etc.
	Diverted traffic due to construction site	Impact of diverted traffic

CASE STUDY

CRITERIA FILTERING

Group	ID	Criterion
Economic	ECO_1	Enforcement costs
	ECO_2	Viability of investment
	ECO_3	Profitable operations
	ECO_4	Transportation costs
	ECO_5	Adaptation costs
	ECO_6	Quality and reliability of deliveries of construction materials
Environmental	ENV_1	Air pollution
	ENV_2	Climate change
	ENV_3	Noise pollution
	ENV_4	Vibration
	ENV_5	Water pollution
	ENV_6	Biodiversity
	ENV_7	Landscape quality
Societal	SOC_1	Labour conditions
	SOC_2	Social and political acceptance by citizens of impacts generated
	SOC_3	Business climate during construction works
	SOC_4	Societal attractiveness
	SOC_5	Social and economic revitalisation
	SOC_6	Security of construction material goods during construction works
	SOC_7	Traffic safety impacts
	SOC_8	Impact on the traffic and accessibility

CASE STUDY

CRITERIA FINAL SELECTION

- Ask citizens to select 9 relevant criteria, i.e., $\beta = 9$
- Give scores to the criteria based on relevant level in a $1-5$ Likert scale

$S'_{21\times40}, s_{i,j} \in [0..5]$

- Column-wise normalization

$S'_{21\times40} \rightarrow S''_{21\times40}$

CASE STUDY

CRITERIA FINAL SELECTION

- Rescaling

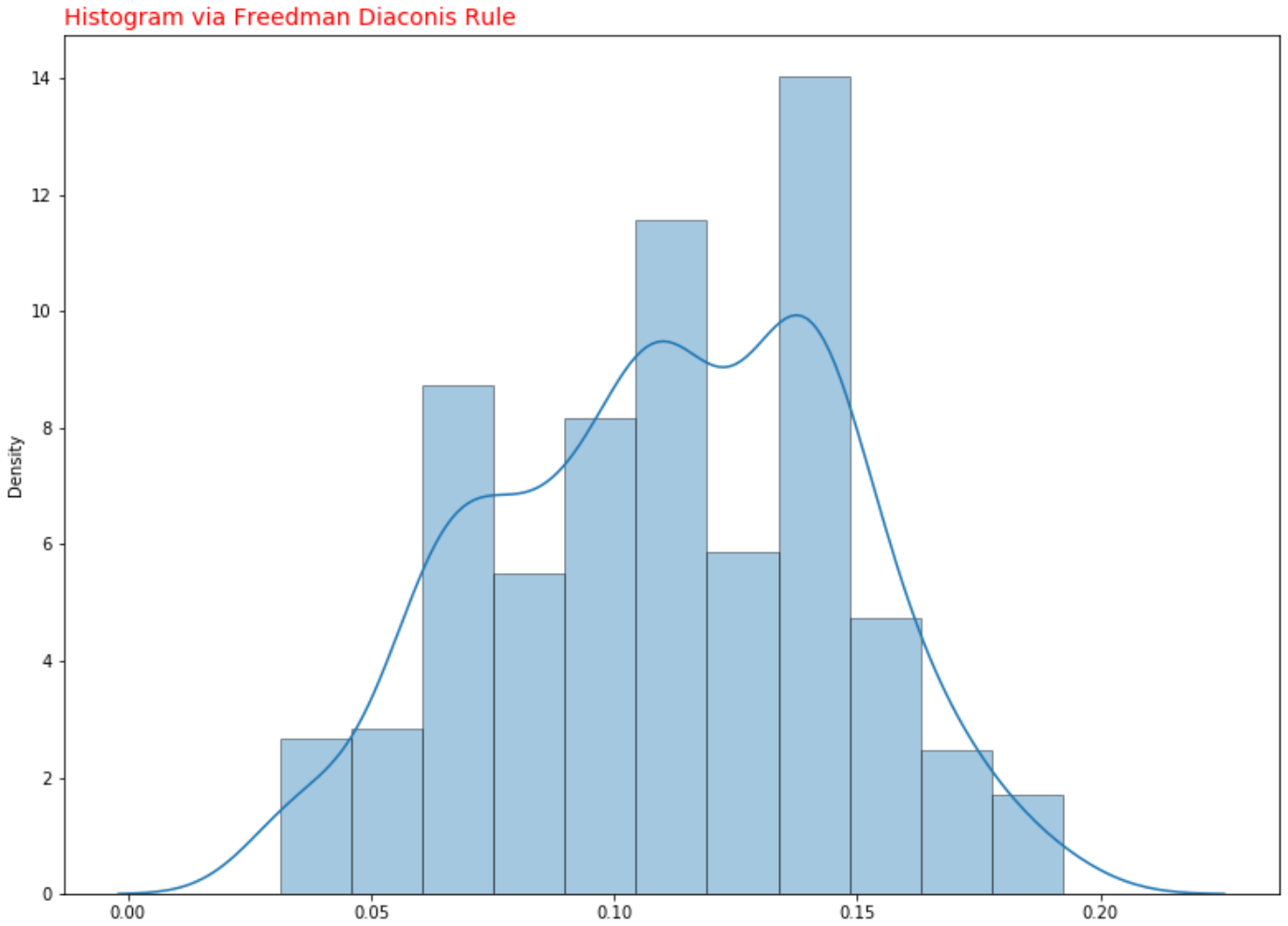
$$o_{\beta \cdot m} = \left[\min_{s''\backslash 0} s'', \ldots, \max_{s''} s''\right]$$

Histogram + Freedman–Diaconis rule:

$$Bin\ width = 2 \cdot \frac{IQR(o)}{\sqrt[3]{\beta \cdot m}}$$

Edges:

```
[0.03125 0.04589161 0.06053322
0.07517483 0.08981643 0.10445804
0.11909965 0.13374126 0.14838287
0.16302448 0.17766608 0.19230769]
```



CASE STUDY

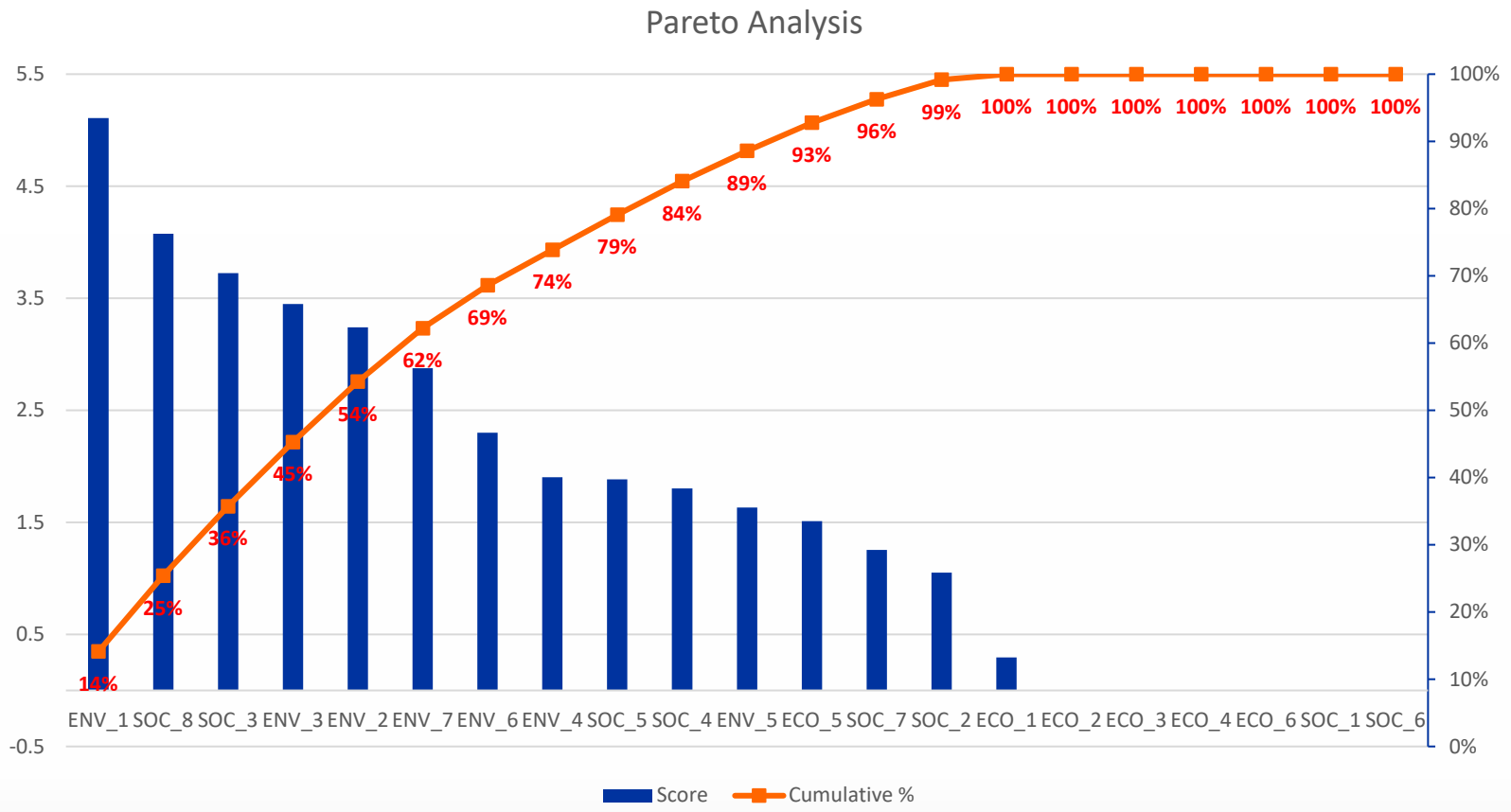
CRITERIA FINAL SELECTION – PROFILE DISTRIBUTION MATRIX

	γ	1	2	3	4	5	6	7	8	9	10	11	$\bar{v}$	σ	p
c_1	28%	45%	0	45%	9%	0	0	0	0	0	0	0	2.18	1.11	0.29
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	55%	0	27%	0	14%	45%	14%	0	0	0	0	0	4.18	1.43	1.51
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	75%	0	0	0	0	0	21%	3%	31%	24%	17%	3%	8.24	1.43	5.11
	63%	0	0	12%	0	8%	4%	16%	52%	4%	0	4%	7.08	1.90	3.24
	65%	0	4%	4%	0	8%	8%	17%	42%	4%	13%	0	7.25	1.94	3.45
	48%	0	0	16%	11%	21%	5%	21%	21%	5%	0	0	5.89	1.89	1.90
⋮	58%	13%	0	13%	4%	13%	35%	13%	0	0	9%	0	5.21	2.38	1.63
	83%	0	9%	39%	0	18%	33%	0	0	0	0	0	4.27	1.48	2.30
	83%	0	0	18%	24%	15%	30%	6	0	0	0	0	5.06	1.58	2.88
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	20%	0	0	0	0	25%	38%	13%	25%	0	0	0	6.38	1.11	1.05
	78%	0	0	19%	0	6%	0	6%	45%	19%	0	3%	7.06	2.26	3.73
	73%	21%	0	7%	3%	7%	41%	3%	7%	3%	3%	3%	5.21	2.72	1.80
	43%	0	0	18%	6%	12%	0	6%	41%	12%	6%	0	6.71	2.27	1.89
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	50%	0	25%	5%	30%	0	0	15%	20%	5%	0	0	4.95	2.43	1.26
c_{21}	83%	0	0	0	18%	9%	12%	15%	27%	9%	3%	6%	6.9	2.00	4.08

$$p = \gamma \cdot (\bar{v} - \sigma)$$

CASE STUDY

CRITERIA FINAL SELECTION – PARETO ANALYSIS



CASE STUDY

CRITERIA FINAL SELECTION

Ranking	Criteria ID	Zone
1	Air pollution	Definitive zone
2	Impact on the traffic and accessibility	
3	Business climate during construction works	
4	Noise pollution	
5	Climate change	
6	Landscape quality	Flexible zone
7	Biodiversity	
8	Vibration	
9	Social and economic revitalisation	

CASE STUDY

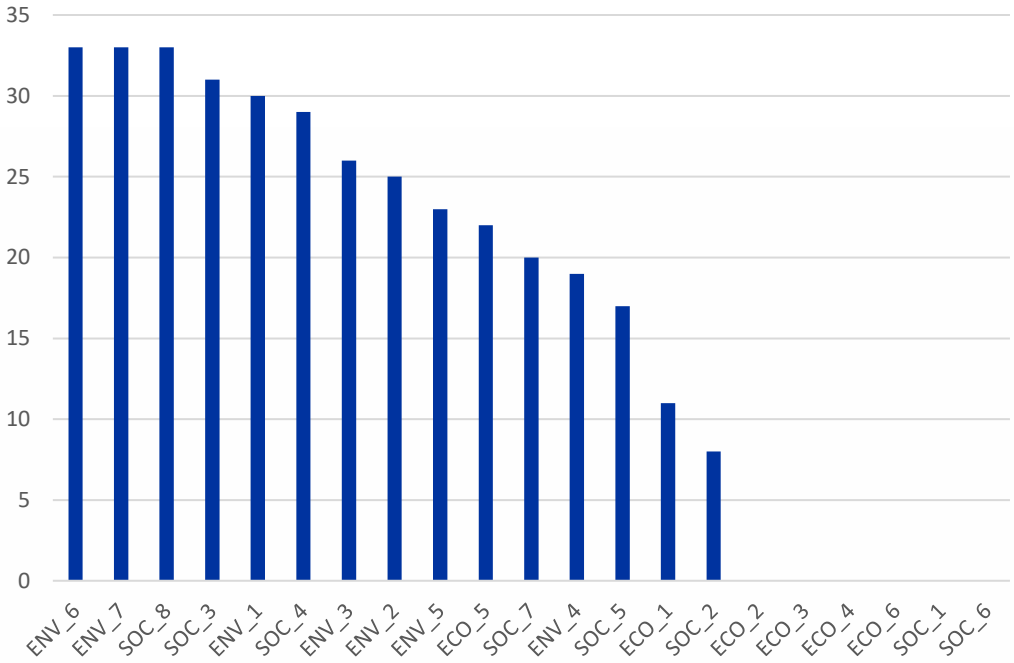
COMPARISON

Criteria set proposed in the Conventional Way							
Biodiversity	Landscape quality	Impact on the traffic and accessibility	Business climate during construction works	**Societal attractiveness**	Air pollution	Noise pollution	Climate change

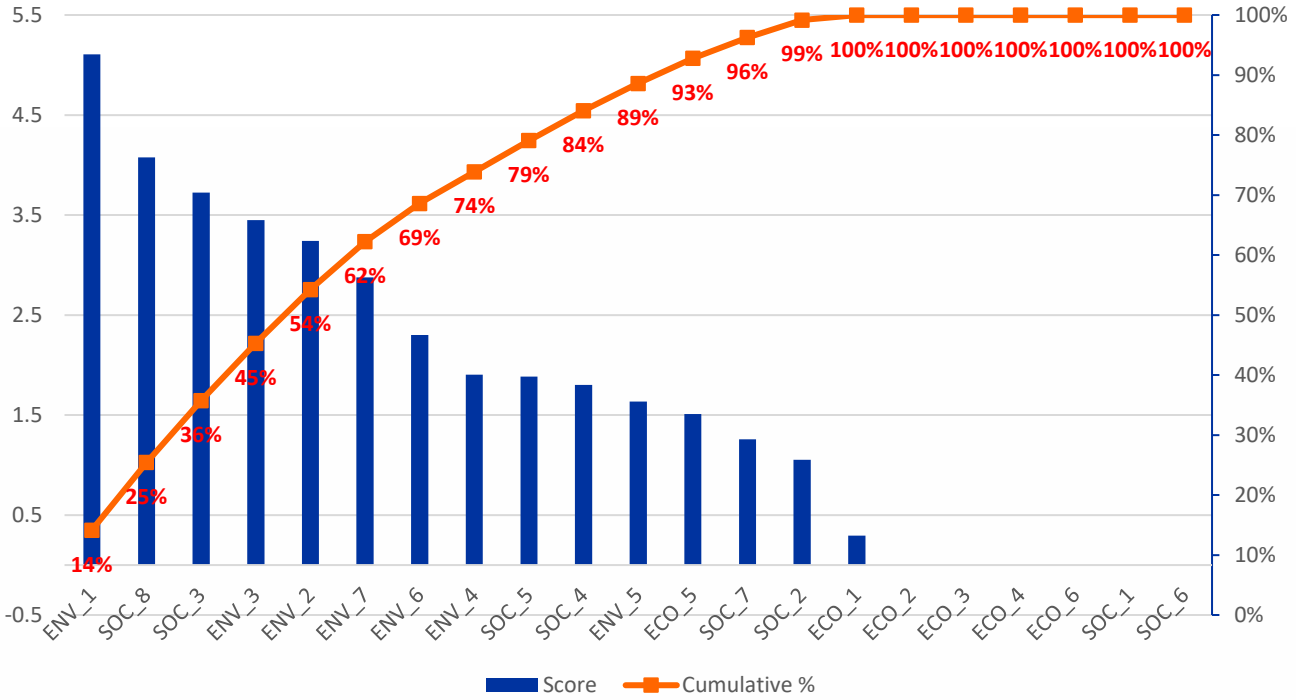
Criteria set proposed based on the Criteria Deciding Model								
Definitive zone					Flexible zone			
Air pollution	Impact on the traffic and accessibility	Business climate during construction works	Noise pollution	Climate change	Landscape quality	Biodiversity	**Vibration**	**Social and economic revitalisation**

CASE STUDY
COMPARISON

Criteria selection in conventional way



Criteria selection model



CONCLUSION

IDENTIFY POSSIBLE CONSENSUS

- A new criteria pre-processing framework;
- A formal guideline serves for identifying criteria set for decision making;
- Explicit ranking list without ties;
- Guarantee the equality of stakeholders and consider the distribution of scores on criteria.

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