MASTER BASE MODULE – Communication Systems Group, Prof. Dr. Burkhard Stiller

University of Zurich[UZH]

Improvement and Testing of TrAdeCIS

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Chapter 1

Introduction

Main scope of reported work is to test and improve existing implementation of TrAdeCIS web-based application, both from front-end and back-end prospective. To ensure correctness of the application's visual appearance, front-end application part was tested and improved. To assess correctness of the underlying application logic, real-world test cases have been collected and application performance in response has been reported. Finally, as a suggestion for the future research, thoughts on theoretical background for automatic trade-off system have been reported.

Chapter 2

Visual appearance of TrAdeCIS

Original implementation of TrAdeCIS web application featured a bug related to algorithm input matrix appearance. Figure 2.1 outlines the issue:

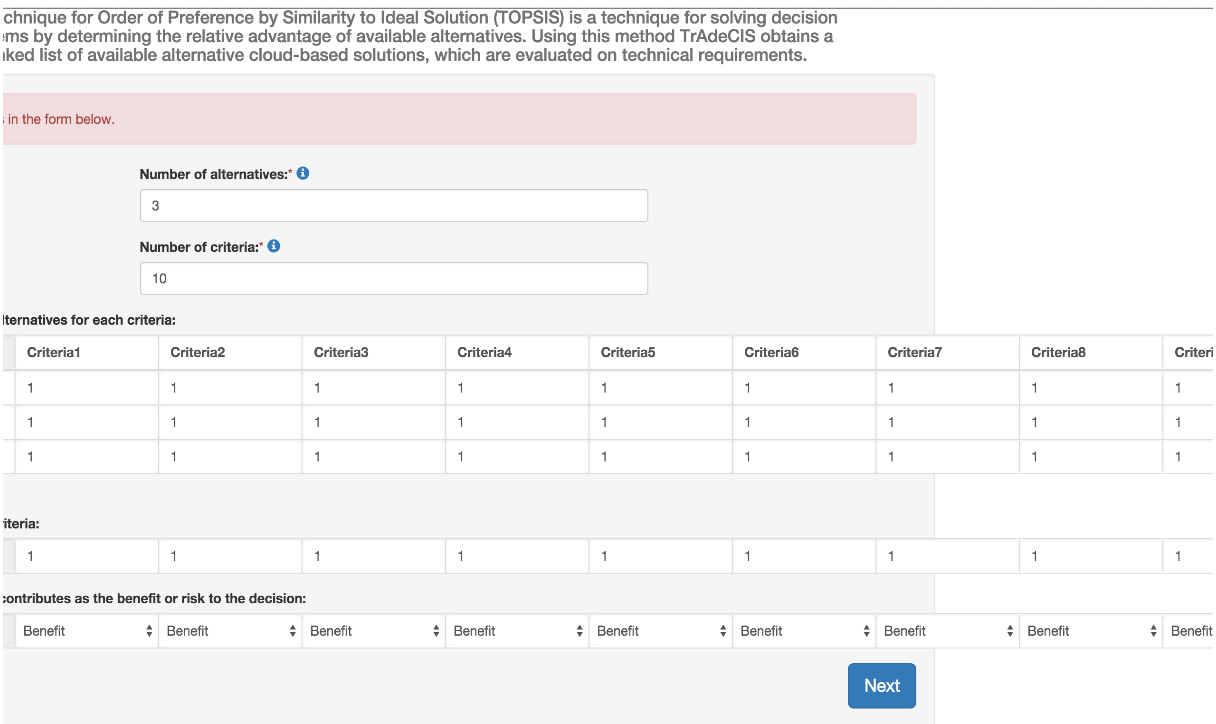


Figure 2.1: Scaling issue on TOPSIS tab

As shown on the Figure 2.1, the TOPSIS algorithm input matrix goes out of enclosing element bounds once the `'Number of criteria'` parameter is set too large ($>= 6$) value. To handle aforementioned issue gracefully, I have decided to make underlying HTML element, the gray box enclosing all fields, scrollable to force all children elements to stay persistent within the box bounds. To achieve that, files *project_folder/TrAdeCIS/mcda/templates/mc* and *project_folder/TrAdeCIS/static/css/style.css* have been modified.
To allow Bootstrap `div class="well"` to become scrollable, I had to set the following CSS option:

```
col-xs-12 .well {
   overflow:  auto;
}
```

After applying mentioned changes, TOPSIS wizard page's appearance is shown on the Figure 2.2:

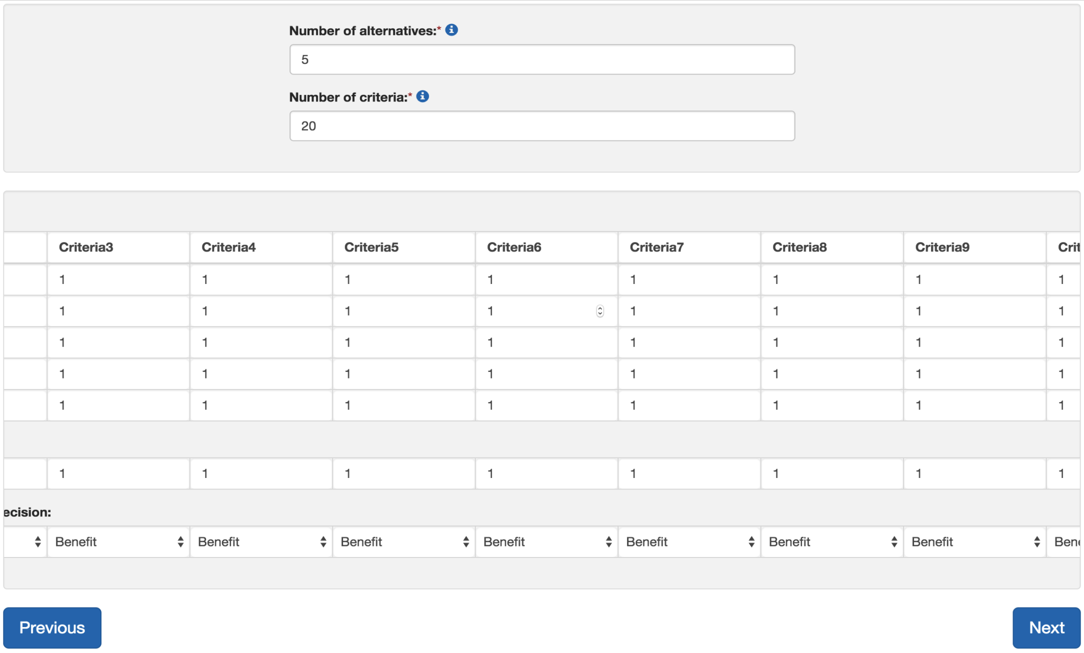


Figure 2.2: Fixed issue on TOPSIS tab

One might notice that fields for `'Number of alternatives'` and `'Number of criteria'` has been moved to separate gray box as well as `'Previous'` and `'Next'` buttons have been taken out of the box. This was done in order to achieve consistency in design: while table hosting parameters for criteria and alternatives adjusts it's size dynamically, input fields for number of criteria, alternatives and buttons are static and don't vary in size. To achieve this effect, the structure and the code in *project_folder/TrAdeCIS/mcda/templates/mcda/wizard.html* have been significantly changed.
There have been further alterations to code invisible to eye to ensure proper sizing of the HTML elements.

All code changes and additions related to the TOPSIS wizard have been performed in the following files:

- *project_folder/TrAdeCIS/mcda/templates/mcda/wizard.html*
- *project_folder/TrAdeCIS/mcda/templates/mcda/wizard − topsis.html*
- *project_folder/TrAdeCIS/static/bundles/wizard − topsis.js*
- *project_folder/TrAdeCIS/static/css/style.css*

Multiple changes have been applied to ANP wizard page as well. Similar to the TOPSIS case, ANP inter-dependency matrix exposed auto-scaling issue:

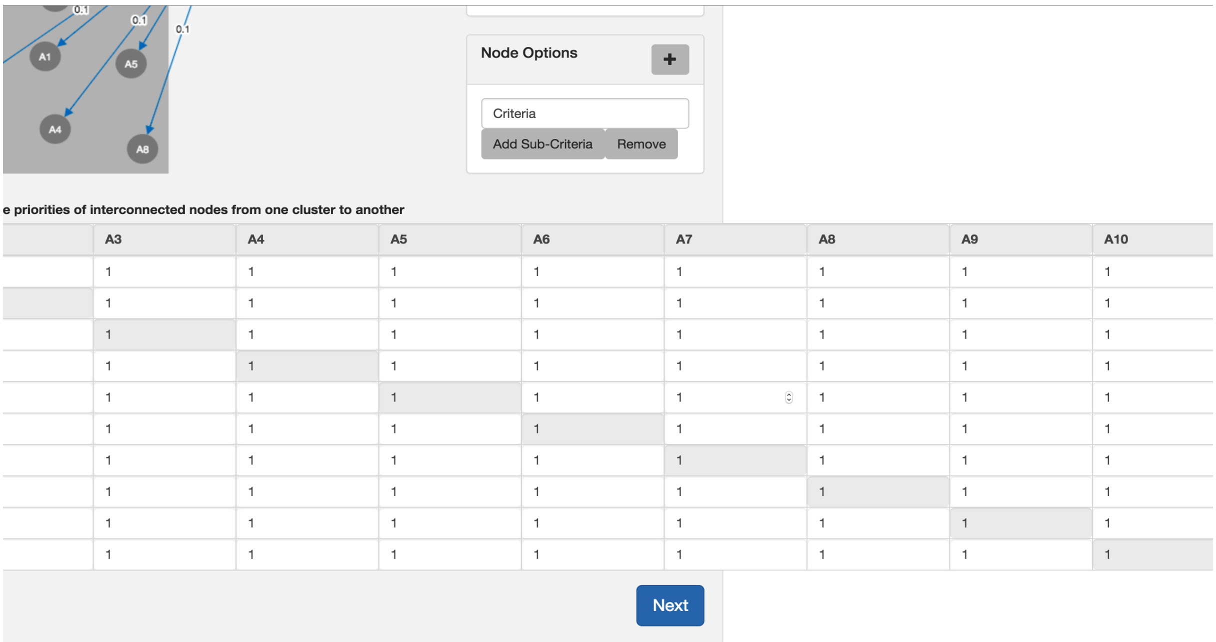


Figure 2.3: Issue on ANP tab

The issue has been solved in a similar manner to the TOPSIS issue, but, in order to make design more neat, I have added JavaScript code to dynamically generate space and surrounding box for inter-dependency matrix box. The following code has been added to *project_folder/TrAdeCIS/static/bundles/wizard − anp.js* to dynamically add and remove space for inter-dependency matrix:

```
/*code displays inter-dependency matrix once graph node is selected*/
this.cy.on('select', 'node', function () {
        $('#tableLabel').show();
        document.getElementsByClassName("col-md-12")[1].className += " well";
          ...
     });

/*code hides inter-dependency matrix once graph node is deselected*/
this.cy.on('unselect', 'node', function () {
        $('#tableLabel').hide();
        document.getElementsByClassName("col-md-12")[1].className = "col-md-12";
      ...
      });
```

Also, one might notice spacing issues with **Add Sub-Criteria** and **Remove** buttons. These and many other small issues with layout, sizing and spacing have been fixed in CSS style file.
Figure 2.4 shows updated version of ANP wizard page:

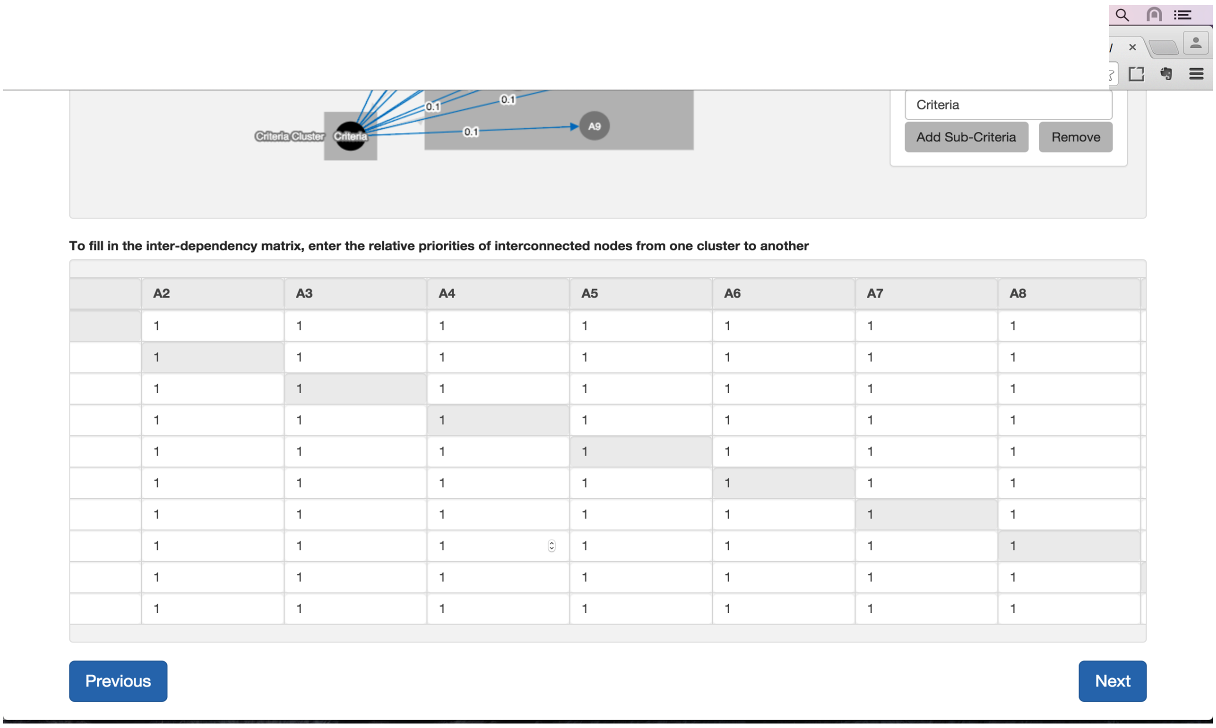


Figure 2.4: Updated ANP tab

List of files that have been modified during modification of ANP wizard:

- *project_folder/TrAdeCIS/mcda/templates/mcda/wizard.html*
- *project_folder/TrAdeCIS/mcda/templates/mcda/wizard − anp.html*
- *project_folder/TrAdeCIS/mcda/templates/mcda/graph.html*

- $project\_folder/TrAdeCIS/mcda/templates/mcda/inter\_dependency\_matrix.html$ (new file)
- $project\_folder/TrAdeCIS/static/bundles/wizard-anp.js$
- $project\_folder/TrAdeCIS/static/css/style.css$

Similar issues as displayed on ANP and TOPSIS tabs occurred with the decision detail result page. In particular, once decision maker wishes to modify ANP values and clicks on any node, the table containing the matrix was going out of screen bounds. Issue with displaying TOPSIS matrix with a large number of columns persisted. Solution is pretty much identical to the case with ANP and TOPSIS, so I won't be providing any figures or code snippets.
Following files were modified to ensure correct visualization of decision detail page:

- $project\_folder/TrAdeCIS/mcda/templates/mcda/decision-detail.html$
- $project\_folder/TrAdeCIS/static/bundles/decision-detail.js$

Chapter 3

Evaluation

To test and evaluate correctness of TrAdeCIS, 7 real-world test cases have been collected and inputted into existing implementation. Output of both algorithms have been reported as well as the trade-off options.
The test cases don't follow a random structure: each test case showcases different features of TOPSIS and ANP algorithms in order to a). test the feature; b). make it easier for readers to understand underlying complexity of algorithms. Decision structure process for TOPSIS is persistent: only parameters that can be varied are number of alternatives, number of criteria, relative importance and Risk(R)/Benefit(B) setting. However, ANP is a much more complex algorithm and it can be difficult for newcomers to fully understand what inner-dependency, outer-dependency relationships represent. Provided test cases will explore feedback relationship from alternatives to criteria, make use of nested clustering and inter-cluster matrix determining importance of every cluster wrt to goal. An example of outer-dependency connecting criteria-to-alternative as well as criteria-to-criteria cluster will be given. Finally, test cases will be exploring examples of inner-dependencies aka self-loops which capture relationship between criteria within a single cluster.

3.1 Test Case 1 - Buying a car

This test case aims to simulate and model typical decision making process when TrAdeCIS user tries to decide which car to buy.
There are 4 alternatives to consider: BMW 3-Series 320d, Mercedes C-Class 180, Audi A4 2.0 and Jaguar XE 2.0d. Criteria for choosing a car are: Minimal Price($), Running Costs, Fuel Consumption(l/100km), Interior Design, Exterior Design, CO2 Emissions(g/km) parameters.
With a TOPSIS, we aim to compare technical properties, hence, in the given scenario, TOPSIS will be used to value the car by Fuel Consumption and $CO2$ Emissions. One might argue that Interior Design and Exterior Design should also be evaluated by TOPSIS rather than ANP, however, in this concrete scenario, Interior Design and Exterior Design criteria represent an overall impression of decision maker of the car design, rather than

focusing on particular feature i.e. does the car have leather seats? does the car have high fidelity sound system?.

Alternatives	Fuel Consumption(	CO2 Emissions(g/k
Mercedes C180	5.6	116
Audi A4 2.0	4.2	99
BMW 320d	4.3	110
Jaguar XE 2.0d	4.1	109

Relative Priority	4	2
Risk(R)/Benefit(B)	Risk	Risk

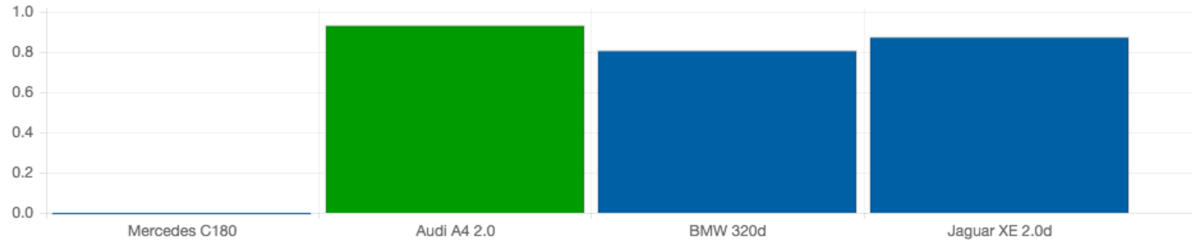


Figure 3.1: TOPSIS matrix for car buying process

Figure 3.1 shows corresponding values for every alternative and relative priorities set. For example, relative priority of Fuel Consumption is 4, which means that it is Moderately Important Plus criteria and, by setting it as a Risk, decision maker represents that higher fuel consumption is a negative factor.
With ANP, we aim to model economical and environmental factors. In this test-case, economical factors will be Price($) and Running Costs($). Design criteria, such as Exterior and Interior Design, can be treated as environmental factors: they don't represent any particular feature that each car has or doesn't have, they rather attempt to value decision maker impressions on design of every car and are subject to taste.

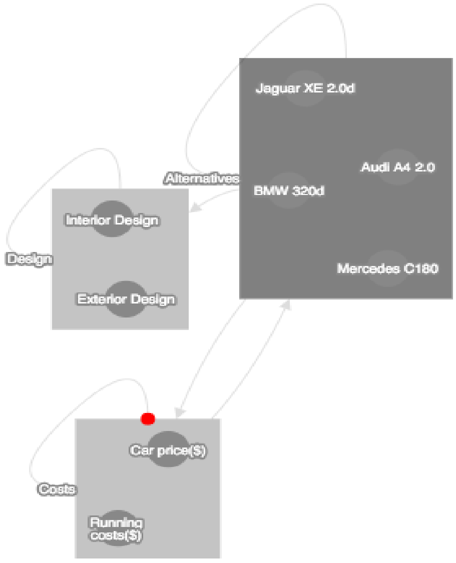


Figure 3.2: ANP graph for car buying process

Figure 3.2 shows the graph that has been built by decision maker. There are 3 clusters, one with Alternatives, one for Design criteria and one for Costs criteria. Each cluster also has a self-loop added.
Figure 3.3 shows inner-dependency matrix for Alternatives:

Alternatives	Mercedes C180	Audi A4 2.0	BMW 320d	Jaguar XE 2.0d
Mercedes C180	1	1	1	1
Audi A4 2.0	1	1	1	1
BMW 320d	1	1	1	1
Jaguar XE 2.0d	1	1	1	1

Figure 3.3: Inner-dependency matrix for Alternatives cluster in car buying process

The matrix depicted on Figure 3.3 has a following contextual meaning: for some unknown reason, decision maker gives more preference to one of the alternative, and he wishes not to or he cannot express it as a criteria. Given inner-dependency matrix would allow to capture described factor. However, in the given test-case, all values have been set to 1 because there's no "hidden" factor that makes decision maker to lean towards any particular car.

Design	Interior Design	Exterior Design
Interior Design	1	0.5
Exterior Design	2	1

Figure 3.4: Inner-dependency matrix for Design cluster in car buying process

Figure 3.4 depicts inner-dependency matrix for criteria cluster called Design. The matrix allows to capture inner relationships inside Design cluster i.e. how more/less important is Interior Design over Exterior Design.

Costs	Car price($)	Running costs($)
Car price($)	1	3
Running costs($)	0.3333333333333	1

Figure 3.5: Inner-dependency matrix for Costs cluster in car buying process

Figure 3.5 depicts inner-dependency matrix for criteria cluster called Costs. The matrix allows to capture inner relationships inside Costs cluster i.e. how more/less important is Car Price over Running Costs.

Mercedes C180	Interior Design	Exterior Design
Interior Design	1	5
Exterior Design	0.2	1
Mercedes C180	Car price($)	Running costs($)
Car price($)	1	3
Running costs($)	0.3333333333333	1

Figure 3.6: Mercedes C180 matrix for car buying process

The matrix depicted on Figure 3.6 captures relationship between alternative and criteria. Given the example, real-world context would be: Mercedes C180 is 5 times better at Interior Design rather than at Exterior Design, Mercedes C180 is 3 times better priced than it is when it comes to Running Costs.
Following 3 figures represent matrix capturing identical relationships for other alternatives.

Jaguar XE 2.0d	Interior Design	Exterior Design
Interior Design	1	2
Exterior Design	0.5	1
Jaguar XE 2.0d	Car price($)	Running costs($)
Car price($)	1	0.5
Running costs($)	2	1

Figure 3.7: Jaguar XE 2.0 matrix for car buying process

Audi A4 2.0	Interior Design	Exterior Design
Interior Design	1	0.5
Exterior Design	2	1
Audi A4 2.0	Car price($)	Running costs($)
Car price($)	1	0.5
Running costs($)	2	1

Figure 3.8: Audi A4 2.0 matrix for car buying process

BMW 320d	Interior Design	Exterior Design
Interior Design	1	0.25
Exterior Design	4	1
BMW 320d	Car price($)	Running costs($)
Car price($)	1	2
Running costs($)	0.5	1

Figure 3.9: BMW 320d matrix for car buying process

Finally, Figure 3.10 ,Figure 3.11, Figure 3.12 and Figure 3.13 represent dependency relationship between criteria and alternative. Let's consider matrix on Figure 3.12 as an example: Audi A4 is twice better than Mercedes C180 in Exterior Design, 3 times worse compared to BMW 320d and twice 2 times worse than Jaguar XE.

Car price($)	Mercedes C180	Audi A4 2.0	BMW 320d	Jaguar XE 2.0d
Mercedes C180	1	1.0121091632084	0.9094523766510	1.0762696547991
Audi A4 2.0	0.98803571428	1	0.8985714285680	1.0633928571527
BMW 320d	1.09956279809	1.11287758347	1	1.1834260731358
Jaguar XE 2.0d	0.92913518052	0.94038623005	0.84500419815	1

Figure 3.10: Car price matrix for car buying process

Running costs($)	Mercedes C180	Audi A4 2.0	BMW 320d	Jaguar XE 2.0d
Mercedes C180	1	0.5	0.3333333333333	0.3333333333333
Audi A4 2.0	2	1	0.5	0.5
BMW 320d	3	2	1	2
Jaguar XE 2.0d	3	2	0.5	1

Figure 3.11: Running costs matrix for car buying process

Exterior Design	Mercedes C180	Audi A4 2.0	BMW 320d	Jaguar XE 2.0d
Mercedes C180	1	0.5	0.2	0.25
Audi A4 2.0	2	1	0.3333333333333	0.5
BMW 320d	5	3	1	2
Jaguar XE 2.0d	4	2	0.5	1

Figure 3.12: Exterior Design matrix for car buying process

Interior Design	Mercedes C180	Audi A4 2.0	BMW 320d	Jaguar XE 2.0d
Mercedes C180	1	4	2	2
Audi A4 2.0	0.25	1	0.5	1
BMW 320d	0.5	2	1	2
Jaguar XE 2.0d	0.5	1	0.5	1

Figure 3.13: Interior Design matrix for car buying process

The output of ANP algorithm:

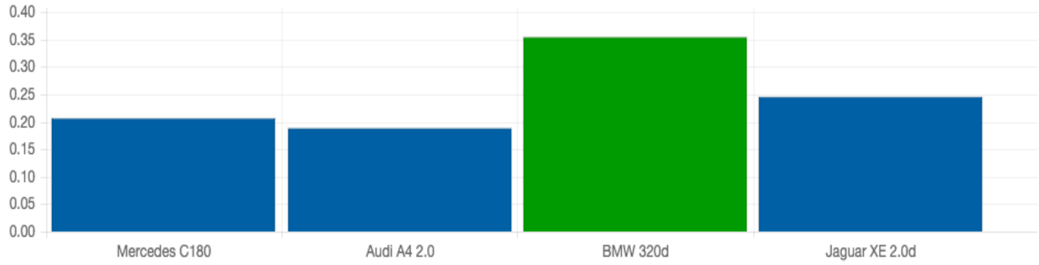


Figure 3.14: ANP Result for car buying process

TOPSIS has valued Audi A4 as the most optimal choice while ANP has rated BMW 320d as the best alternative. Clearly, this is due to the fact that Audi is good at fuel consumption and CO2 emissions, BMW has a significant advantage in design, running costs and price. Matching the output of both algorithms would be possible only in the case if decision maker will remove some criteria from consideration: Audi outruns BMW on all TOPSIS criteria, while BMW performs better on every single criteria subject to consideration by ANP.

3.2 Test Case 2 - Buying a new flat

This test case aims to simulate and model typical decision making process when TrAdeCIS user decides which flat to purchase.
There are 7 alternatives to consider: Pererva st., 43, Dmitrovskoe highway, 94/4, Yaroslavskaya st., 4/2, Marshal Savitsky st., 4/1, Radial 6-th st., 7, Rodionovskaya st., 2, Davidkovskaya st., 3. Criteria for choosing a flat are: Price($), Maintenance Costs, Safety, Facilities, Air Pollution, Noise Level, Distance to City Center(km), Distance to Tube(km), Number of Rooms, Number of Bathrooms, Floor, Living Area(sq.m), Furnished(boolean).
TOPSIS is used to value technical parameters, hence, will be used to value the flat by: Distance to City Center(km), Distance to Tube(km), Number of Rooms, Number of Bathrooms, Floor, Living Area(sq.m), Furnished(boolean). Interesting criteria is Furnished: decision maker attempts not to value overall quality of each flat furnishing, but rather indicate whether a flat is furnished or doesn't have any furniture at all. To represent this criteria numerically, decision maker treats it as a boolean value: 1 - furnished, 0 - not furnished. Figure 3.15 shows matrix for TOPSIS algorithm:

Alternatives	Living Area(sq.m)	Distance to tube(kr	Distance to city cei	No. of rooms	No. of bathrooms	Floor	Furnished
Yaroslavskaya st.,	39.6	1.3	15.1	1	1	11	0
Dmitrovskoe highw	37	4.6	17.5	1	1	14	0
Marshal Savistky s	42.3	12.6	37.1	2	1	10	1
Radial 6-th st.,7	35.7	2.5	27.6	1	1	3	0
Pererva st., 43	44.8	0.12	20.1	2	1	3	0
Rodionovskaya st.,	48.9	7.2	24.8	2	2	9	1
Davidkovskaya st.,	54.3	2.5	10.3	2	1	19	1
Relative Priority	3	7	5	1	3	2	5
Risk(R)/Benefit(B)	Benefit	Risk	Risk	Benefit	Benefit	Benefit	Benefit

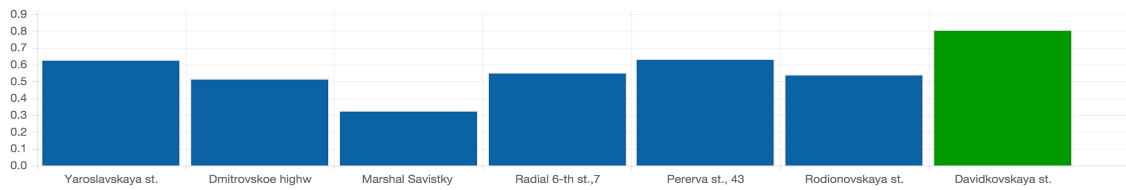


Figure 3.15: TOPSIS matrix for flat buying process

TrAdeCIS uses ANP to value economical and environmental factors. In the given scenario, Safety, Facilities, Air Pollution, Noise Level will be environment criteria for the

flat buying process and are meant to assess how alternatives relatively compare to each other. For example, flat at Davidkovskaya st. is 2 twice safer than the alternative located on Dmitrovskoye highway. Safety isn't a property which every flat either has either does not, neither it has an exact numerical value - it is just used to assess safety of the flat's locations compared to each other.
Flat Price($) and Maintenance Costs are, clearly, economical factors and, hence, should also be assessed by ANP rather TOPSIS.
Figure 3.16 represents an ANP graph representing relationships between criteria and alternatives:

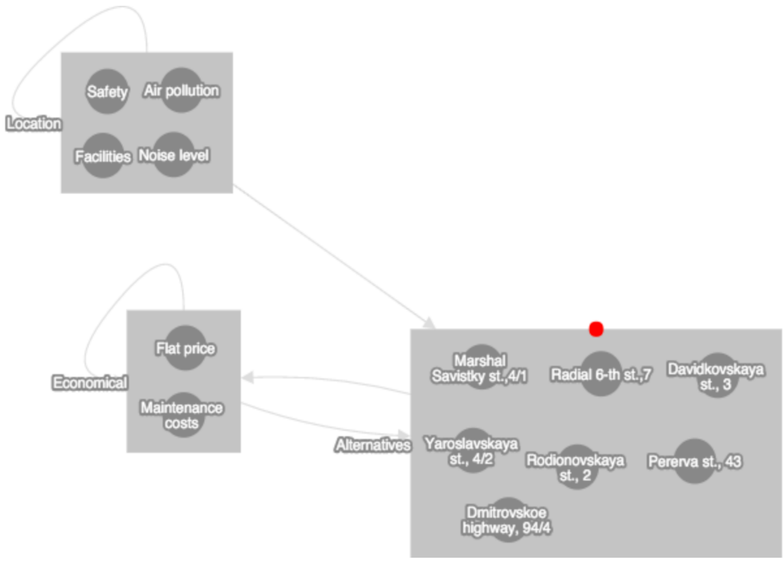


Figure 3.16: ANP graph for flat buying process

Criteria clusters, namely Economical and Location, have self loops added in order to capture inter-cluster dependencies e.g. in Economical Cluster, Maintenance Costs is 3 times contributes 3 times more towards decision than Flat Price. Inner-dependency matrices for Economical and Location clusters are captured on Figure 3.17 and Figure 3.18 respectively.

Economical	Maintenance costs	Flat price
Maintenance costs	1	3
Flat price	0.3333333333333	1

Figure 3.17: Inner-dependency matrix for Economical cluster in flat buying process

Location	Air pollution	Noise level	Facilities	Safety
Air pollution	1	1	0.5	0.25
Noise level	1	1	0.5	0.3333333333333
Facilities	2	2	1	0.5
Safety	4	3	2	1

Figure 3.18: Inner-dependency matrix for Location cluster in flat buying process

Next, we are going to value alternatives in terms of Economical criteria, Flat price and Maintenance costs as shown on Figure 3.19 and Figure 3.20. Noticeably, values of inner-dependency matrix for Flat price parameter seem to be very strange. This values are calculated by taking real flat prices and comparing them. For example, price of the flat on Dmitrovskoye highway is 94800$ and price of the on Yaroslavskaya st. is 92165$, hence, Yaroslavskaya st. is better than Dmitrovskoye highway on Flat price criteria for 94800$/92165$ = 1.02859002875530. Other matrix entries are calculated in similar fashion.

Flat price	Yaroslavskaya st.,	Dmitrovskoe highw	Marshal Savistky s	Radial 6-th st.,7	Pererva st., 43	Rodionovskaya st.,	Davidkovskaya st.,
Yaroslavskaya st.,	1	1.0285900287530	1.0595996310984	0.9932512341965	1.1121358433335	1.2529810665698	1.3777789833576
Dmitrovskoe highw	0.97220464135	1	1.0301476793311	0.9656434599180	1.0812236286925	1.2181540084423	1.3394831223629
Marshal Savistky s	0.94375268795	0.97073460443	1	0.9373835220915	1.0495811915047	1.1825042495309	1.3002826189510
Radial 6-th st.,7	1.00679462111	1.03557890827	1.06679920911	1	1.1196923850049	1.2614945981691	1.3871404695143
Pererva st., 43	0.8991707317	0.92487804878	0.95276097561	0.89310243902	1	1.1266439024445	1.2388585365894
Rodionovskaya st.,	0.79809665659	0.82091426295	0.8456629229	0.79271048917	0.88759189823	1	1.0996008001327
Davidkovskaya st.,	0.72580581652	0.74655662569	0.76906357543	0.72090752305	0.80719466385	0.90942094611	1

Figure 3.19: Flat price matrix for flat buying process

Maintenance costs	Yaroslavskaya st.,	Dmitrovskoe highw	Marshal Savistky s	Radial 6-th st.,7	Pererva st., 43	Rodionovskaya st.,	Davidkovskaya st.,
Yaroslavskaya st.,	1	1	0.3333333333333	0.5	1	2	3
Dmitrovskoe highw	1	1	0.3333333333333	0.5	1	2	3
Marshal Savistky s	3	3	1	2	2	6	9
Radial 6-th st.,7	2	2	0.5	1	2	5	7
Pererva st., 43	1	1	0.5	0.5	1	3	5
Rodionovskaya st.,	0.5	0.5	0.1666666666666	0.2	0.3333333333333	1	2
Davidkovskaya st.,	0.3333333333333	0.3333333333333	0.1111111111111	0.1428571428571	0.2	0.5	1

Figure 3.20: Maintenance costs matrix in flat buying process

Lastly, alternatives are valued against Location cluster criteria: Noise level, Facilities, Air pollution and Safety.

Safety	Yaroslavskaya st.,	Dmitrovskoe highw	Marshal Savistky s	Radial 6-th st.,7	Pererva st., 43	Rodionovskaya st.,	Davidkovskaya st.,
Yaroslavskaya st.,	1	1	4	3	2	0.5	0.3333333333333
Dmitrovskoe highw	1	1	4	3	2	0.5	0.3333333333333
Marshal Savistky s	0.25	0.25	1	0.6666666666666	0.3333333333333	0.1428571428571	0.125
Radial 6-th st.,7	0.3333333333333	0.3333333333333	1.5	1	0.5	0.2	0.1666666666666
Pererva st., 43	0.5	0.5	3	2	1	0.25	0.2
Rodionovskaya st.,	2	2	7	5	4	1	0.5
Davidkovskaya st.,	3	3	8	6	5	2	1

Figure 3.21: Safety matrix in flat buying process

Facilities	Yaroslavskaya st.,	Dmitrovskoe highw	Marshal Savistky s	Radial 6-th st.,7	Pererva st., 43	Rodionovskaya st.,	Davidkovskaya st.,
Yaroslavskaya st.,	1	1	3	2	0.5	0.25	0.1666666666666
Dmitrovskoe highw	1	1	3	2	0.5	0.25	0.1666666666666
Marshal Savistky s	0.3333333333333	0.3333333333333	1	0.5	0.25	0.1428571428571	0.1111111111111
Radial 6-th st.,7	0.5	0.5	2	1	0.3333333333333	0.2	0.1428571428571
Pererva st., 43	2	2	4	3	1	0.3333333333333	0.25
Rodionovskaya st.,	4	4	7	5	3	1	0.5
Davidkovskaya st.,	6	6	9	7	4	2	1

Figure 3.22: Facilities matrix in flat buying process

Air pollution	Yaroslavskaya st.,	Dmitrovskoe highw	Marshal Savistky s	Radial 6-th st.,7	Pererva st., 43	Rodionovskaya st.,	Davidkovskaya st.,
Yaroslavskaya st.,	1	4	0.5	3	2	3	3
Dmitrovskoe highw	0.25	1	0.2	0.5	0.3333333333333	0.5	0.5
Marshal Savistky s	2	5	1	4	3	5	5
Radial 6-th st.,7	0.3333333333333	2	0.25	1	1.5	2	2
Pererva st., 43	0.5	3	0.3333333333333	0.6666666666666	1	1	1
Rodionovskaya st.,	0.3333333333333	2	0.2	0.5	1	1	0.5
Davidkovskaya st.,	0.3333333333333	2	0.2	0.5	1	2	1

Figure 3.23: Air pollution matrix in flat buying process

Noise level	Yaroslavskaya st.,	Dmitrovskoe highw	Marshal Savistky s	Radial 6-th st.,7	Pererva st., 43	Rodionovskaya st.,	Davidkovskaya st.,
Yaroslavskaya st.,	1	3	0.5	2	1.5	5	5
Dmitrovskoe highw	0.3333333333333	1	0.2	0.3333333333333	0.5	0.2	0.2
Marshal Savistky s	2	5	1	3	4	1	1
Radial 6-th st.,7	0.5	3	0.3333333333333	1	1.5	0.3333333333333	0.3333333333333
Pererva st., 43	0.6666666666666	2	0.25	0.6666666666666	1	0.25	0.25
Rodionovskaya st.,	0.2	5	1	3	4	1	1
Davidkovskaya st.,	0.2	5	1	3	4	1	1

Figure 3.24: Noise level matrix in flat buying process

Output of ANP algorithm:

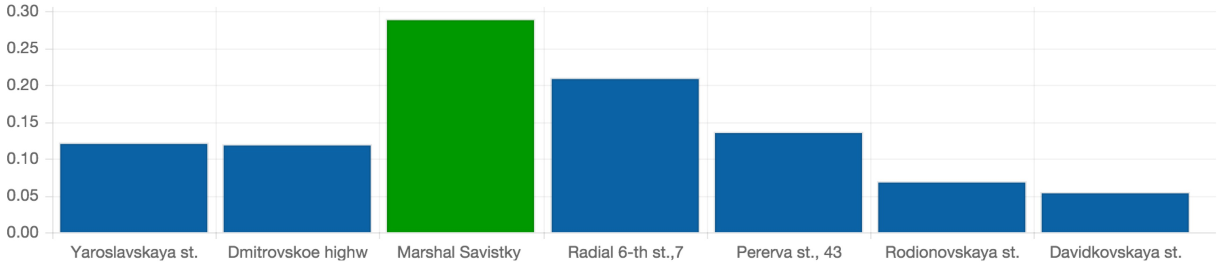


Figure 3.25: ANP result for flat buying process

From Figure 3.15 and Figure 3.25, we can observe that output results of algorithms don't match. Clearly, Davidkovskaya st. 3 performed best in TOPSIS because it is largest flat on high floor located close to city center, but it is the most expensive option which TOPSIS doesn't know. A potential trade-off is to sacrifice importance of living area and number of rooms and pick flat at Marshal Savitskiy st.,4/1 which is a flat with low cost, cheap maintenance and low level of air pollution. Of course, if decision maker is happy to pay high price, then flat at Davidkovskaya st. is going to be the best option.

3.3 Test Case 3 - Buying a new smartphone

This test case is dedicated to imitate decision making process when a client i.e. decision maker decides to buy a new smartphone. Given alternatives are: iPhone 6S, Samsung Galaxy S6, Sony Xperia Z5 Premium, HTC One M9 and LG G4. The criteria that are important to decision maker: Built-in Memory(GB), RAM(GB), Camera Resolution(MP), Water and dust resistance(boolean), Weight(g), Battery Capacity(mAh), Durability, Repairability, OS Design and Phone Design.
Technical features, such as Built-in Memory(GB), RAM(GB), Camera Resolution(MP), Water and dust resistance(boolean), Weight(g), Battery Capacity(mAh), of smartphones are going to be valued by TOPSIS.

Alternatives	Built-in Memory(GE	RAM(GB)	Camera Resolution	Water and dust res	Battery capacity(m	Weight(g)
LG G4	32	3	16	0	3000	155
iPhone 6S	16	2	12	0	1810	129
Sony Xperia Z5 Pre	32	3	23	1	3430	180
Samsung Galaxy S	32	3	16	0	2550	138
HTC One M9	32	3	20	0	2840	157
Relative Priority	1	1	3	3	1	4
Risk(R)/Benefit(B)	Benefit	Benefit	Benefit	Benefit	Benefit	Risk

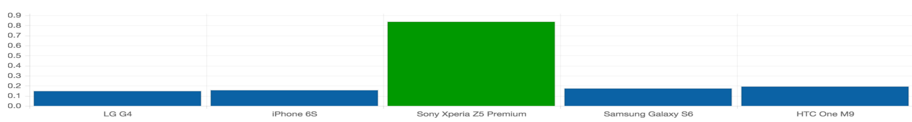


Figure 3.26: TOPSIS matrix for smartphone buying process

ANP is used to value economical and environmental factors in TrAdeCIS system. Since decision maker hasn't defined any economical criteria (economical factors don't necessarily have to be present), ANP will be used to value only environmental factors. In the given test case, Durability, Repairability, OS Design and Phone Design are going to be environmental factors. One might argue that Water and dust resistance(boolean) criteria also needs to be valued by ANP because it is a measure of device's durability. However, this criteria doesn't assess how alternatives perform relative to each other e.g. iPhone 6S is 2 times more resistant to water and dust rather than Samsung Galaxy S6, but rather represents a technical parameter of each alternative: smartphone is either water and dust proof(1 boolean value), either it is not(0 boolean value).
Figure 3.27 shows an ANP graph:

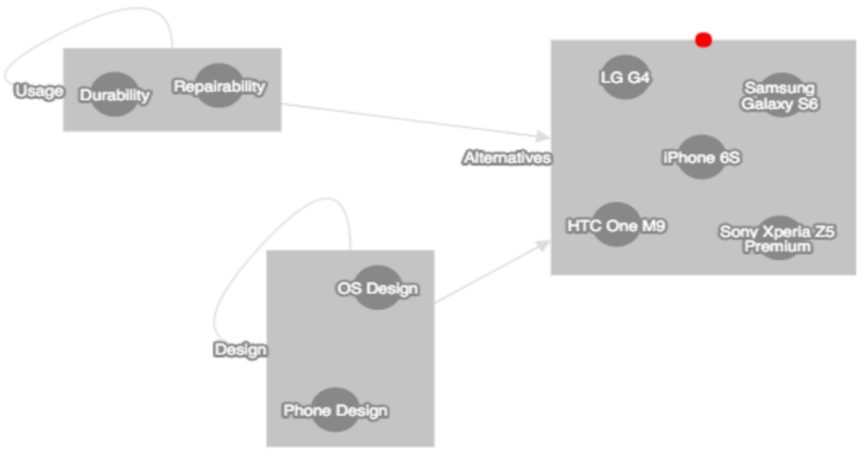


Figure 3.27: ANP graph for smartphone buying process

ANP graph features 3 clusters, Usage, Design and Alternatives. Self loops on Usage and Design clusters are representing inner-dependency between cluster elements. Arrows connecting Usage and Design clusters to Alternatives cluster represent outer-dependencies i.e. Alternatives are valued in terms of Design and Usage criteria.
Matrices capturing clusters' inner-dependencies are shown on Figure 3.28 and Figure 3.29:

Usage	Repairability	Durability
Repairability	1	0.3333333333333
Durability	3	1

Figure 3.28: Inner-dependency matrix for Usage cluster in smartphone buying process

Design	OS Design	Phone Design
OS Design	1	3
Phone Design	0.3333333333333	1

Figure 3.29: Inner-dependency matrix for Design cluster in smartphone buying process

Outer-dependencies for Usage and Design clusters (in this case, valuation of alternatives with respect to criteria) is depicted on Figures 3.30,3.30,3.32,3.33:

Durability	LG G4	iPhone 6S	Sony Xperia Z5 Pre	Samsung Galaxy S(	HTC One M9
LG G4	1	2	0.5	1	1
iPhone 6S	0.5	1	0.25	0.5	0.5
Sony Xperia Z5 Pre	2	4	1	2	2
Samsung Galaxy S(	1	2	0.5	1	1
HTC One M9	1	2	0.5	1	1

Figure 3.30: Durability matrix in smartphone buying process

Repairability	LG G4	iPhone 6S	Sony Xperia Z5 Pre	Samsung Galaxy S(	HTC One M9
LG G4	1	4	2	2	4
iPhone 6S	0.25	1	0.5	0.5	1
Sony Xperia Z5 Pre	0.5	2	1	1	2
Samsung Galaxy S(	0.5	2	1	1	2
HTC One M9	0.25	1	0.5	0.5	1

Figure 3.31: Repairability matrix in smartphone buying process

OS Design	LG G4	iPhone 6S	Sony Xperia Z5 Pre	Samsung Galaxy S(	HTC One M9
LG G4	1	0.25	1	1	0.5
iPhone 6S	4	1	4	4	2
Sony Xperia Z5 Pre	1	0.25	1	1	0.5
Samsung Galaxy S(	1	0.25	1	1	0.5
HTC One M9	2	0.5	2	2	1

Figure 3.32: OS Design matrix in smartphone buying process

Phone Design	LG G4	iPhone 6S	Sony Xperia Z5 Pre	Samsung Galaxy S(	HTC One M9
LG G4	1	0.2	0.3333333333333	0.3333333333333	0.1428571428571
iPhone 6S	5	1	3	2	0.4
Sony Xperia Z5 Pre	3	0.3333333333333	1	1	0.2
Samsung Galaxy S(	3	0.5	1	1	0.2
HTC One M9	7	2.5	5	5	1

Figure 3.33: Phone Design matrix in smartphone buying process

Result of ANP:

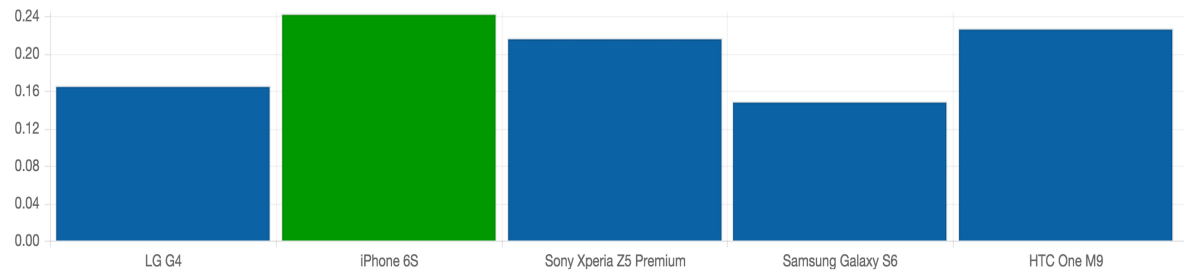
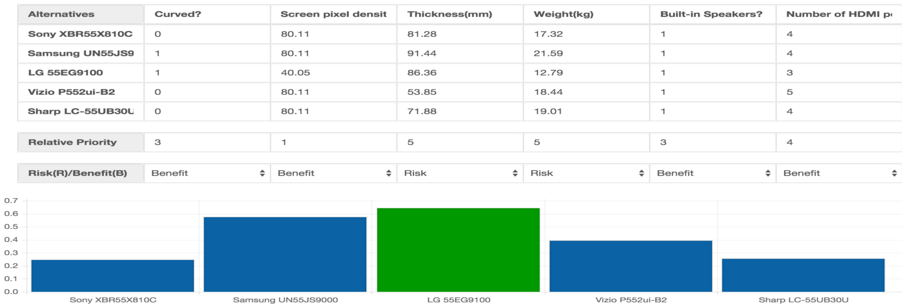


Figure 3.34: ANP result for smartphone buying process

The output isn't surprising: best-looking from technical specification side, Sony Xperia Z5 Premium, is a TOPSIS choice. iPhone 6S, best-looking device with IOS on board, got top ranked by ANP, however, Sony Xperia Z5 has also performed well in ANP due to significantly better durability and repairability than iPhone 6S.
The best trade-off solution in the given case would be to sacrifice importance of OS design and body design to make outputs of both algorithms match.

3.4 Test Case 4 - Buying a new Smart TV

This test case attempts to simulate typical decision making process when TrAdeCIS user wants to purchase a new Smart TV. Alternatives that decision maker takes into consideration are: Sony XBR55X810C, Samsung UN55JS9000, LG 55EG9100, Vizio P552ui-B2, Sharp LC-55UB30U. The alternatives have complicated naming and, thus, later will be referred simply as Sony instead of Sony XBR55X810C or Samsung instead of Samsung UN55JS9000. Decision maker takes following criteria in consideration: Curved (boolean), Thickness(mm), Weight(kg), Screen pixel density(ppi), Built-in Speakers(boolean), Number of HDMI ports, Interface Design, TV Body Design, Price, Software Setup (how easy is it to setup TV software-wise) and Physical Setup (how easy is it to mount a TV or assemble a TV stand).
In a similar manner to previous test cases, technical criteria are going to be valued by TOPSIS:



Alternatives	Curved?	Screen pixel densit	Thickness(mm)	Weight(kg)	Built-in Speakers?	Number of HDMI p
Sony XBR55X810C	0	80.11	81.28	17.32	1	4
Samsung UN55JS9	1	80.11	91.44	21.59	1	4
LG 55EG9100	1	40.05	86.36	12.79	1	3
Vizio P552ui-B2	0	80.11	53.85	18.44	1	5
Sharp LC-55UB30U	0	80.11	71.88	19.01	1	4
Relative Priority	3	1	5	5	3	4
Risk(R)/Benefit(B)	Benefit	Benefit	Risk	Risk	Benefit	Benefit

Figure 3.35: TOPSIS matrix for Smart TV buying process

Built-in Speakers and Curved boolean criteria represent presence of technical features and, thus, are evaluated by TOPSIS. For example, does Samsung feature curved screen (1 - yes, 0 - no).
ANP is used to value environmental and economical factors. Price($) is, clearly, an economical factor and, consequently, will be evaluated by ANP. Software Setup, Physical Setup, TV Body Design and Software Design will be valued by ANP as well because these criteria are to assess how well alternatives perform relative to each other. For example, Design is a subjective opinion of decision maker, there is no way to quantitatively assess design of TV. Same applies to other aforementioned criteria and, thus, they will be valued by ANP.
Figure 3.36 shows ANP graph capturing the network structure of TV buying process:

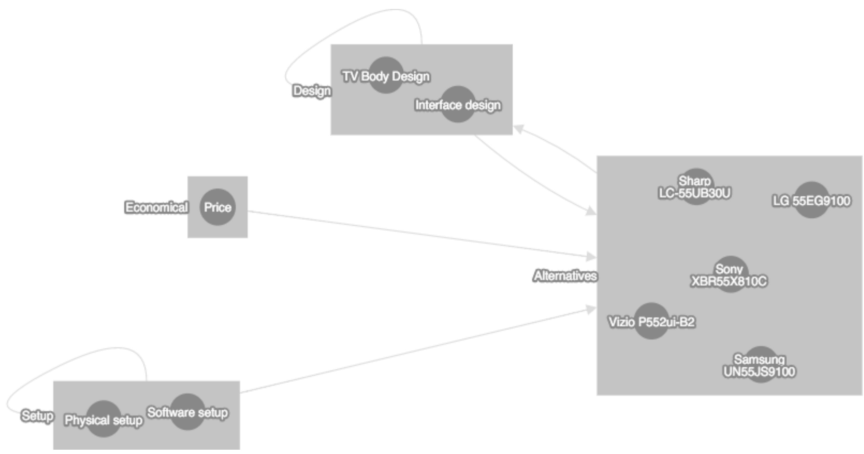


Figure 3.36: ANP graph for Smart TV buying process

An interesting feature that makes this use case distinct from previous is the usage of inter-cluster matrix. Inter-cluster matrix allows to capture relative importance of network clusters with respect to the goal i.e. how much each cluster contributes towards the goal of decision making process compared to other clusters.
Figure 3.37 depicts the inter-cluster matrix for Smart TV buying process:

Cluster Matrix	Alternatives	Design	Setup	Economical
Alternatives	1	1	1	1
Design	1	1	2	2
Setup	1	0.5	1	0.5
Economical	1	0.5	2	1

Figure 3.37: Inter-cluster ANP matrix for Smart TV buying process

Inner-dependency matrices for every cluster are given below:

Setup	Physical setup	Software setup
Physical setup	1	3
Software setup	0.3333333333333	1

Figure 3.38: Inner-dependency matrix for Setup cluster in Smart TV buying process

Design	TV Body Design	Interface design
TV Body Design	1	2
Interface design	0.5	1

Figure 3.39: Inner-dependency matrix for Design cluster in Smart TV buying process

Outer-dependency matrices are shown on Figures 3.40, 3.41, 3.42, 3.43, 3.44:

Interface design	Sony XBR55X810C	Samsung UN55JS9	LG 55EG9100	Vizio P552ui-B2	Sharp LC-55UB30L
Sony XBR55X810C	1	2	2	3	2
Samsung UN55JS9	0.5	1	0.5	1	0.25
LG 55EG9100	0.5	2	1	0.5	0.75
Vizio P552ui-B2	0.3333333333333	1	2	1	0.3333333333333
Sharp LC-55UB30L	0.5	4	1.3333333333333	3	1

Figure 3.40: Interface Design matrix in Smart TV buying process

TV Body Design	Sony XBR55X810C	Samsung UN55JS9	LG 55EG9100	Vizio P552ui-B2	Sharp LC-55UB30L
Sony XBR55X810C	1	0.25	0.25	2	1
Samsung UN55JS9	4	1	1	6	3
LG 55EG9100	4	1	1	6	3
Vizio P552ui-B2	0.5	0.1666666666666	0.1666666666666	1	0.5
Sharp LC-55UB30L	1	0.3333333333333	0.3333333333333	2	1

Figure 3.41: Software Design matrix for Design cluster in Smart TV buying process

Software setup	Sony XBR55X810C	Samsung UN55JS9	LG 55EG9100	Vizio P552ui-B2	Sharp LC-55UB30L
Sony XBR55X810C	1	0.5	1	3	2
Samsung UN55JS9	2	1	2	4	2
LG 55EG9100	1	0.5	1	3	2
Vizio P552ui-B2	0.3333333333333	0.25	0.3333333333333	1	0.5
Sharp LC-55UB30L	0.5	0.5	0.5	2	1

Figure 3.42: Software Setup matrix in Smart TV buying process

Physical setup	Sony XBR55X810C	Samsung UN55JS9	LG 55EG9100	Vizio P552ui-B2	Sharp LC-55UB30L
Sony XBR55X810C	1	0.5	0.5	0.3333333333333	2
Samsung UN55JS9	2	1	0.5	0.6666666666666	1
LG 55EG9100	2	2	1	1	2
Vizio P552ui-B2	3	1.5	1	1	2.5
Sharp LC-55UB30L	0.5	1	0.5	0.4	1

Figure 3.43: Physical Setup matrix in Smart TV buying process

Price	Sony XBR55X810C	Samsung UN55JS9	LG 55EG9100	Vizio P552ui-B2	Sharp LC-55UB30L
Sony XBR55X810C	1	2.2012012012142	2.001001001	0.86086086086	0.7997997998
Samsung UN55JS9	0.45429740791	1	0.90904956798	0.39108685766	0.36334697589
LG 55EG9100	0.4997498749377	1.1000500250190	1	0.43021510755	0.39969984992
Vizio P552ui-B2	1.1616279069779	2.5569767442028	2.3244186046715	1	0.92906976744
Sharp LC-55UB30L	1.2503128911135	2.7521902378588	2.5018773467144	1.0763454317918	1

Figure 3.44: Price matrix in Smart TV buying process

Result of ANP:

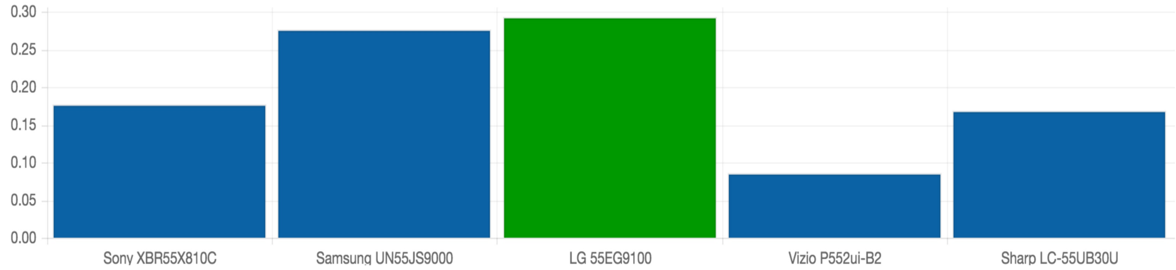


Figure 3.45: ANP result for Smart TV buying process

Outputs of both, TOPSIS and ANP, have matched and there's no trade-off to be made: LG Smart TV has best price/value ratio among considered alternatives.

3.5 Test Case 5 - Buying a new laptop

Making a right choice which laptop to buy can be very difficult nowadays due to many alternatives on the market and multiple technical and non-technical criteria that have to be considered. Decision maker faces a choice between different alternatives: MacBook Pro 13" Retina, Fujitsu LifeBook S935, Toshiba KIRA-10D, Lenovo ThinkPad T450S, Acer TravelMate P6. The criteria which are relevant to the decision maker are: Weight(kg), Screen Pixel Density(ppi), Battery Life(minutes), Hard-drive capacity(GB), SSD storage(boolean), CD/DVD drive(boolean), CPU Frequency(GHz), Number of USB ports, Ergonomics, Appearance, Assembly (quality of laptop assembly), Materials (quality of materials used by laptop manufacturer).
TOPSIS will be used to value only technical parameters including SSD drive(boolean) and CD/DVD drive(boolean) because these criteria represent presence of concrete feature in an alternative.
Figure 3.46 shows TOPSIS matrix for laptop buying decision:

Alternatives	Weight(kg)	Screen pixel densit	Battery life(min)	CD/DVD drive?	Hard drive capacity	SSD drive?	CPU frequency(GH	Number of USB po
MacBook Pro 13" F	1.58	227	720	0	128	1	2.7	2
Lenovo T450s	1.59	157	1140	0	256	1	2.6	3
Toshiba KIRA-10D	1.32	166	660	0	256	1	2.4	3
Acer TravelMate P6	1.5	157	540	0	256	1	2.4	3
Fujitsu LifeBook S9	1.24	221	1220	1	128	1	2.7	3
Relative Priority	5	1	3	3	1	3	1	3
Risk(R)/Benefit(B)	Risk	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit

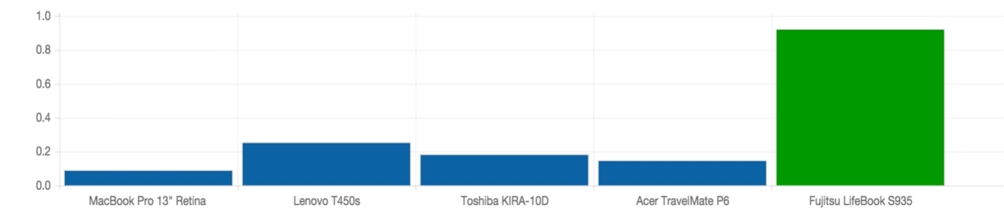


Figure 3.46: TOPSIS matrix for laptop buying process

Ergonomics, Appearance, Assembly and Materials are going to be valued by ANP because they represent subjective opinion of decision maker. For example, MacBook is 2 times better assembled than Lenovo, but look 3 times less appealing than Fujtsu. In addition to that, they can be treated as environmental factors: quality of assembly, ergonomics, quality of materials and appearance are neither technical neither economical parameters. Figure 3.47 shows the ANP graph representing the laptop buying decision network:

Figure 3.47: ANP graph for laptop buying process

This test-case stands out from previous by incorporating the notion of outer-dependency between criteria clusters. Before outer, inter-cluster, dependencies were used to compare alternatives wrt to criteria. This test case captures relationships between criteria i.e. one criteria affects another. Figure 3.47 shows an outer-dependency between Design and Build quality clusters: this represents that appearance and ergonomics of the laptop is affected by quality of assembly and quality of materials used. Underneath matrices depicted on Figure 3.48 and Figure 3.49 capture that relationship:

Appearance	MacBook Pro 13" F	Lenovo T450s	Toshiba KIRA-10D	Acer TravelMate P6	Fujitsu LifeBook S9
MacBook Pro 13" F	1	3	2	6	5
Lenovo T450s	0.33333333333333	1	0.5	4	3
Toshiba KIRA-10D	0.5	2	1	5	4
Acer TravelMate P6	0.16666666666666	0.25	0.2	1	0.4
Fujitsu LifeBook S9	0.2	0.33333333333333	0.25	2.5	1

Appearance	Assembly	Materials
Assembly	1	0.33333333333333
Materials	3	1

Figure 3.48: Appearance matrix in laptop buying process

Ergonomics	MacBook Pro 13" F	Lenovo T450s	Toshiba KIRA-10D	Acer TravelMate P6	Fujitsu LifeBook S9
MacBook Pro 13" F	1	0.33333333333333	2	0.5	2
Lenovo T450s	3	1	4	2	4
Toshiba KIRA-10D	0.5	0.25	1	0.5	2
Acer TravelMate P6	2	0.5	2	1	3
Fujitsu LifeBook S9	0.5	0.25	0.5	0.33333333333333	1

Ergonomics	Assembly	Materials
Assembly	1	2
Materials	0.5	1

Figure 3.49: Ergonomics matrix in laptop buying process

Above matrices on Figure 3.48 and Figure 3.49 represent a valuation of alternatives wrt to Ergonomics and Appearance criteria.
Inner-dependency matrices of criteria clusters are shown on figures below:

Build quality	Assembly	Materials
Assembly	1	2
Materials	0.5	1

Figure 3.50: Inner-dependency matrix for Build Quality cluster in laptop buying process

Design	Ergonomics	Appearance
Ergonomics	1	2
Appearance	0.5	1

Figure 3.51: Inner-dependency matrix for Design cluster in laptop buying process

Outer-dependency matrices that capture evaluation of alternatives wrt to criteria inside Build Quality cluster are shown on Figure 3.52 and Figure 3.53:

Assembly	MacBook Pro 13" F	Lenovo T450s	Toshiba KIRA-10D	Acer TravelMate P6	Fujitsu LifeBook S9
MacBook Pro 13" F	1	2	3	5	5
Lenovo T450s	0.5	1	2	4	4
Toshiba KIRA-10D	0.33333333333333	0.5	1	2.5	2.5
Acer TravelMate P6	0.2	0.25	0.4	1	0.5
Fujitsu LifeBook S9	0.2	0.25	0.4	2	1

Figure 3.52: Assembly matrix in laptop buying process

Materials	MacBook Pro 13" F	Lenovo T450s	Toshiba KIRA-10D	Acer TravelMate P6	Fujitsu LifeBook S9
MacBook Pro 13" F	1	3	2	5	5
Lenovo T450s	0.33333333333333	1	0.66666666666666	3	3
Toshiba KIRA-10D	0.5	1.5	1	4	4
Acer TravelMate P6	0.2	0.33333333333333	0.25	1	0.5
Fujitsu LifeBook S9	0.2	0.33333333333333	0.25	2	1

Figure 3.53: Materials matrix in laptop buying process

ANP result:

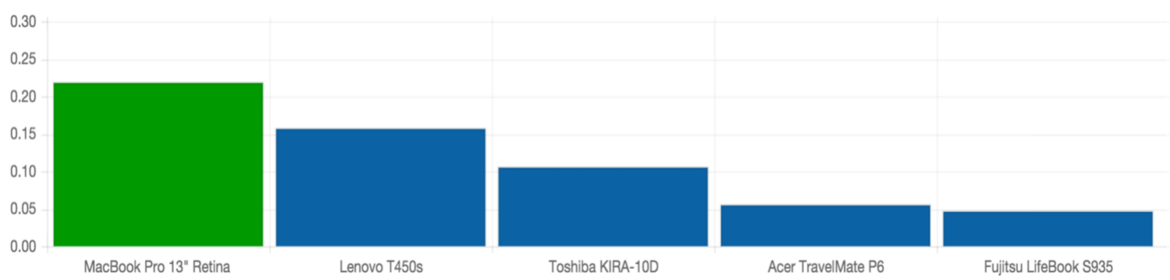


Figure 3.54: ANP result for laptop buying process

According to TOPSIS, Fujitsu laptop turned out to be most technically advanced among alternatives. ANP has ranked MacBook Pro 13" Retina because of high-quality assembly, materials and top-class ergonomics. There can be two potential trade-offs: sacrifice design, ergonomics in favor of technical specifications or vice versa. Also, it is worth mentioning that Lenovo T450S got rated as a second best alternative by both algorithms, so it might be worth considering this option as well.

3.6 Test Case 6 - Choosing a place for vacation

This test case is one of the most complex test cases so far as it has fairly complex ANP network structure.
The goal of the test case is to select best place for vacation.
Alternatives are: Barbados, Crete, Madeira, Tenerife and Lanzarote.
TOPSIS criteria are: Length of flight(min), Length of vacation(days), Timeshift(hrs), Breakfast included?(boolean), Free Wi-Fi?(boolean).
TOPSIS matrix for choosing a vacation destination is shown on Figure 3.55:

Alternatives	Length of flight(mir	Length of vacation(	Timeshift(hrs)	Breakfast included	Free Wi-Fi?
Tenerife	530	7	0	0	1
Lanzarote	2195	7	0	1	1
Barbados	1789	7	4	0	1
Madeira	1255	7	0	1	1
Crete	1430	7	2	0	1
Relative Priority	3	5	3	4	2
Risk(R)/Benefit(B)	Risk	Benefit	Risk	Benefit	Benefit

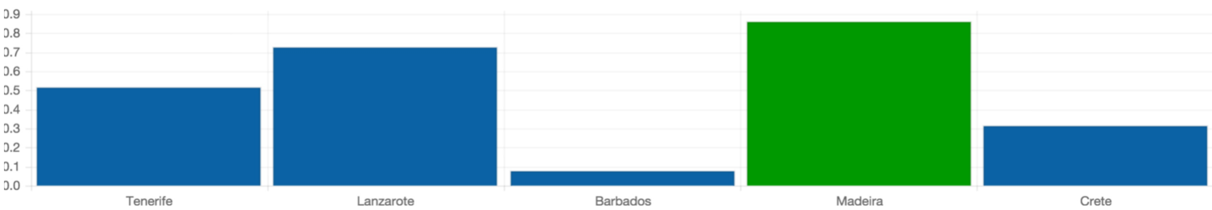


Figure 3.55: TOPSIS matrix for choosing a vacation destination

ANP network structure is organized as following:

- **Economical** cluster: Hotel price($), Flight price($);
- **Living** cluster: Location, **Hotel** cluster:
  - **Hotel** cluster: Facilities, Room;
- **Transportation** cluster: Comfort, Quality;
- **Alternatives** cluster;

Figure 3.56 shows ANP network structure for choosing a vacation destination:

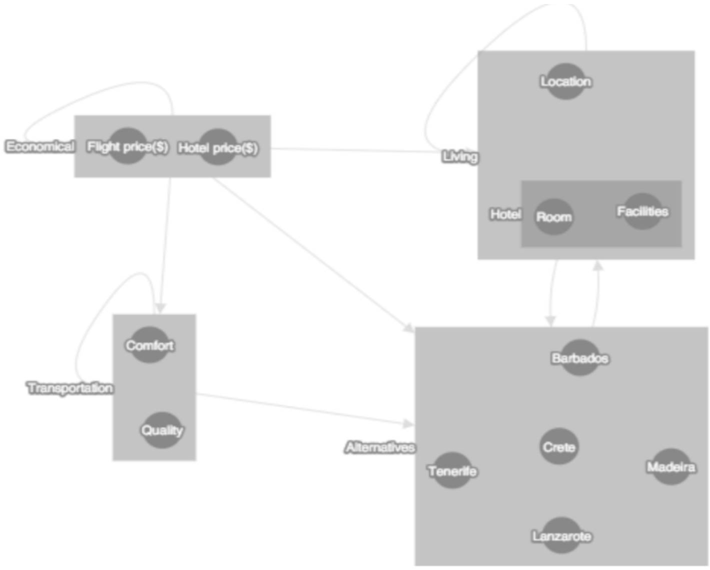


Figure 3.56: ANP network structure for choosing a vacation destination

Living cluster has a bidirectional connection with Alternatives cluster. Living-to-Alternatives relationship represent how well hotels perform wrt to Living cluster criteria compared to each other. Alternative-to-Living relationship represents how well criteria perform compare relative to other for each hotel e.g. hotel at Barbados has twice better rooms then facilities.
Figure 3.57, 3.58, 3.59, 3.60, 3.61 show matrices capturing Alternative-to-Living relationship:

Barbados	Facilities	Room	Location
Facilities	1	2	0.16666666666666
Room	0.5	1	0.125
Location	6	8	1

Figure 3.57: Barbados matrix for choosing a vacation destination

Crete	Facilities	Room	Location
Facilities	1	4	0.5
Room	0.25	1	0.16666666666666
Location	2	6	1

Figure 3.58: Crete matrix for choosing a vacation destination

Tenerife	Facilities	Room	Location
Facilities	1	0.2	0.3333333333333:
Room	5	1	2
Location	3	0.5	1

Figure 3.59: Tenerife matrix for choosing a vacation destination

Lanzarote	Facilities	Room	Location
Facilities	1	3	5
Room	0.3333333333333:	1	0.5
Location	0.2	2	1

Figure 3.60: Lanzarote matrix for choosing a vacation destination

Madeira	Facilities	Room	Location
Facilities	1	0.5	0.2
Room	2	1	0.142857142857l
Location	5	7	1

Figure 3.61: Madeira matrix for choosing a vacation destination

Below figures are showing matrices representing Living-to-Alternatives relationship:

Location	Tenerife	Lanzarote	Barbados	Madeira	Crete
Tenerife	1	0.2	0.1666666666666	0.5	2
Lanzarote	5	1	0.3333333333333:	3	6
Barbados	6	3	1	4	7
Madeira	2	0.3333333333333:	0.25	1	2
Crete	0.5	0.1666666666666	0.142857142857l	0.5	1

Figure 3.62: Location matrix for choosing a vacation destination

Facilities	Tenerife	Lanzarote	Barbados	Madeira	Crete
Tenerife	1	0.2	0.5	0.5	1.666666666666666
Lanzarote	5	1	3	3	7
Barbados	2	0.333333333333333	1	1	2.5
Madeira	2	0.333333333333333	1	1	2.5
Crete	0.6	0.142857142857142	0.4	0.4	1

Figure 3.63: Facilities matrix for choosing a vacation destination

Room	Tenerife	Lanzarote	Barbados	Madeira	Crete
Tenerife	1	0.25	2	2	0.5
Lanzarote	4	1	6	6	3
Barbados	0.5	0.166666666666666	1	1	0.5
Madeira	0.5	0.166666666666666	1	1	2
Crete	2	0.333333333333333	2	0.5	1

Figure 3.64: Room matrix for choosing a vacation destination

To capture inner-dependencies between Living cluster criteria, there are 2 self-loops added to the ANP graph.
Living cluster loop allows to determine which criteria is more important wrt to Living: Hotel sub-cluster or Location. The corresponding matrix is shown on Figure 3.65:

Living	Hotel	Location
Hotel	1	0.5
Location	2	1

Figure 3.65: Inner-dependency matrix for Living cluster in choosing a vacation destination

Hotel sub-cluster self-loop allows to determine which criteria is more important wrt to Hotel: Room or Facilities. The corresponding matrix is shown on Figure 3.66:

Hotel	Facilities	Room
Facilities	1	3
Room	0.333333333333333	1

Figure 3.66: Inner-dependency matrix for Hotel sub-cluster in choosing a vacation destination

As shown on ANP graph depicted on Figure 3.56, Economical cluster has outer-dependencies with Transportation and Living clusters. Relationship between Economical cluster and Transportation cluster can be expressed very simply: more expensive flight = more in-flight comfort. However, Flight Price($) criterion makes no impact at all on the Living cluster.
Aforementioned relationships together with valuation of alternatives are shown on Figure 3.67:

Flight price($)	Tenerife	Lanzarote	Barbados	Madeira	Crete
Tenerife	1	3	5	0.5	2
Lanzarote	0.333333333333333	1	2	0.333333333333333	0.333333333333333
Barbados	0.2	0.5	1	0.166666666666666	0.2
Madeira	2	3	6	1	2
Crete	0.5	3	5	0.5	1

Flight price($)	Comfort	Quality
Comfort	1	3
Quality	0.333333333333333	1

Flight price($)	Facilities	Room	Location
Facilities	1	1	1
Room	1	1	1
Location	1	1	1

Figure 3.67: Flight Price matrix for choosing a vacation destination

Dependency of Living cluster on Economical cluster captures the relationship between quality of hotel rooms, service, location of the hotel criteria and Hotel Price($) criterion and is shown on Figure 3.68:

Hotel price($)	Tenerife	Lanzarote	Barbados	Madeira	Crete
Tenerife	1	4	2	1	1
Lanzarote	0.25	1	0.5	0.25	0.25
Barbados	0.5	2	1	0.5	0.5
Madeira	1	4	2	1	1
Crete	1	4	2	1	1

Hotel price($)	Comfort	Quality
Comfort	1	1
Quality	1	1

Hotel price($)	Facilities	Room	Location
Facilities	1	0.5	4
Room	2	1	5
Location	0.25	0.2	1

Figure 3.68: Hotel Price matrix for choosing a vacation destination

Dependency matrix filled with 1 shows that Hotel Price($) plays no role in the Quality

and Comfort of transportation.
Figure 3.69 shows inner-dependency matrix for Economical cluster:

Economical	Hotel price($)	Flight price($)
Hotel price($)	1	1.5
Flight price($)	0.6666666666666	1

Figure 3.69: Inner-dependency matrix for Economical cluster in choosing a vacation destination

Transportation cluster has no dependencies on other criteria clusters and is used just to assess alternatives wrt to transportation criteria:

Quality	Tenerife	Lanzarote	Barbados	Madeira	Crete
Tenerife	1	2	2	3	1.5
Lanzarote	0.5	1	2	4	2.5
Barbados	0.5	0.5	1	3	2
Madeira	0.3333333333333	0.25	0.3333333333333	1	4
Crete	0.6666666666666	0.4	0.5	0.25	1

Figure 3.70: Quality matrix for choosing a vacation destination

Comfort	Tenerife	Lanzarote	Barbados	Madeira	Crete
Tenerife	1	2	3	0.5	1.5
Lanzarote	0.5	1	2	0.5	2
Barbados	0.3333333333333	0.5	1	0.25	0.3333333333333
Madeira	2	2	4	1	0.5
Crete	0.6666666666666	0.5	3	2	1

Figure 3.71: Comfort matrix for choosing a vacation destination

Figure 3.72 shows inner-dependency matrix for Economical cluster:

Transportation	Comfort	Quality
Comfort	1	3
Quality	0.3333333333333	1

Figure 3.72: Inner-dependency matrix for Transportation cluster in choosing a vacation destination

ANP result:

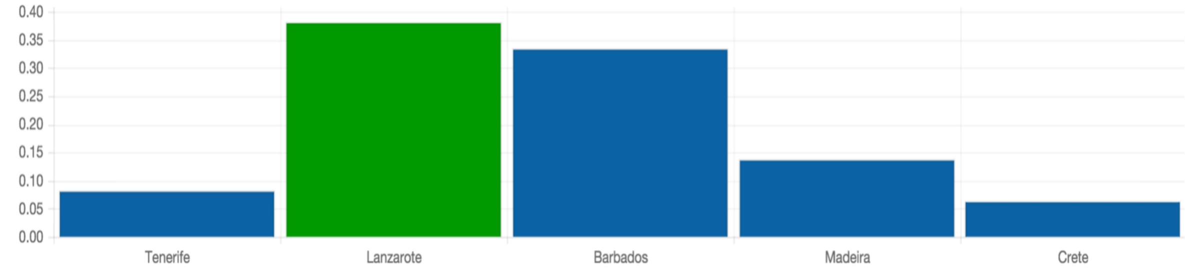


Figure 3.73: ANP result for choosing a vacation destination

While TOPSIS suggests Madeira as a perfect getaway destination, ANP ranked Lanzarote as a top place for spending vacation. Nevertheless, TOPSIS has ranked Lanzarote second with a very close score to Madeira. Lanzarote has a longer flight time compared to Madeira, but, if decision maker is happy to stay slightly longer in the plane, then Lanzarote seems like a perfect vacation destination.

3.7 Test Case 7 - Choosing London to Zurich flight

Last and most complicated test case is dedicated to simulate a decision making process that TrAdeCIS client is likely to go through when choosing a flight from London to Zurich. Alternatives are: Swiss, easyJet, British Airways, Brussels Airlines, airberlin, Air France. TOPSIS criteria are: Flight time(min), Free meal?(boolean), Direct Flight?(boolean), Allowed checked baggage(kg). TOPSIS matrix is shown on Figure 3.74:

Alternatives	Flight time(min)	Direct flight?	Free meal?	Allowed checked b
Swiss	95	1	1	23
easyJet	100	1	0	20
airberlin	100	1	0	23
British Airways	100	1	1	23
Brussels Airlines	205	0	0	23
AirFrance	240	0	1	23
Relative Priority	2	7	3	5
Risk(R)/Benefit(B)	Risk	Benefit	Benefit	Benefit

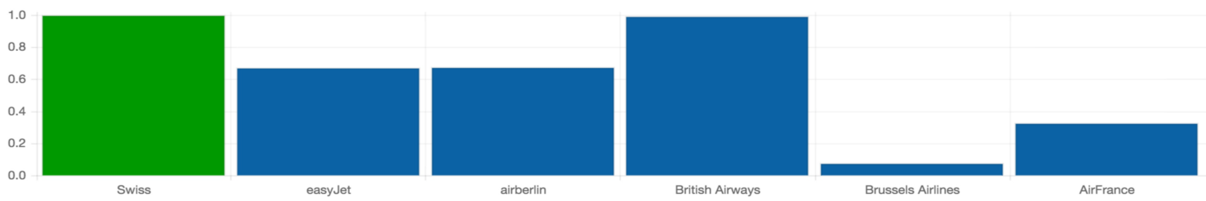


Figure 3.74: TOPSIS matrix for choosing a flight

ANP network is organized as following:

- **Airport** cluster:
  - **Location** cluster: Arrival, Departure;
  - **Facilities** cluster: Arrival, Departure;
- **Economical** cluster: Ticket cost($), Associated Costs($);
- **Other** cluster: Safety, Comfort;
- **Alternatives** cluster:;

ANP graph is shown on Figure 3.75:

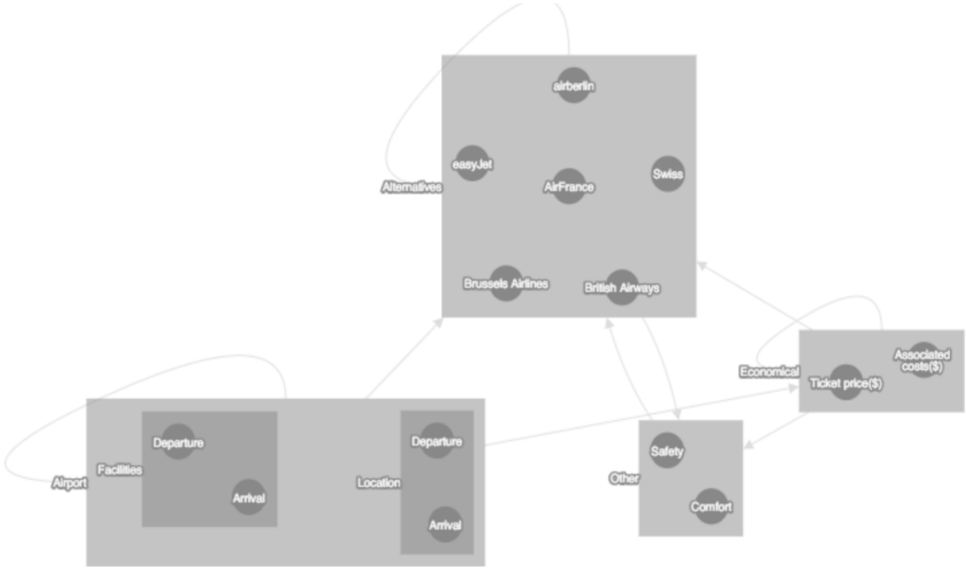


Figure 3.75: ANP network structure for choosing a flight

The given ANP network has a complex structure and, in order to make it clearer, each cluster and it's relationships will be considered separately.
First, let's consider Alternatives cluster. It has a self-loop which allows to capture relationships among alternatives. For example, due to some reason that decision maker can't or doesn't wish to express, he prefers one or multiple alternatives over other. Self-loop on Alternatives cluster is a perfect way to capture this type of relationship:

Alternatives	Swiss	easyJet	airberlin	British Airways	Brussels Airlines	AirFrance
Swiss	1	2	2	1	2	2
easyJet	0.5	1	1	0.5	1	1
airberlin	0.5	1	1	0.5	1	1
British Airways	1	2	2	1	2	2
Brussels Airlines	0.5	1	1	0.5	1	1
AirFrance	0.5	1	1	0.5	1	1

Figure 3.76: Inner-dependency matrix for Alternatives cluster in choosing a flight

In addition to that, Alternatives cluster features a feedback connection Other cluster which allows to highlight particular strength or weakness of each alternative wrt to Other cluster criteria. For example, Swiss is 3 times better at Safety than in Comfort.
Figure 3.77, 3.78, 3.79, 3.80, 3.81, 3.82 show corresponding matrices for every alternative:

Swiss	Safety	Comfort
Safety	1	3
Comfort	0.333333333333333	1

Figure 3.77: Swiss matrix for choosing a flight

airberlin	Safety	Comfort
Safety	1	1
Comfort	1	1

Figure 3.78: airberlin matrix for choosing a flight

AirFrance	Safety	Comfort
Safety	1	0.5
Comfort	2	1

Figure 3.79: AirFrance matrix for choosing a flight

British Airways	Safety	Comfort
Safety	1	2
Comfort	0.5	1

Figure 3.80: British Airways matrix for choosing a flight

Brussels Airlines	Safety	Comfort
Safety	1	0.5
Comfort	2	1

Figure 3.81: Brussels Airlines matrix for choosing a flight

easyJet	Safety	Comfort
Safety	1	1
Comfort	1	1

Figure 3.82: easyJet matrix for choosing a flight

Next cluster to be considered is Economical cluster. It has a self-loop added to establish importance of Ticket Cost($) and Associated Costs($) wrt to Economical. Corresponding matrix is depicted on Figure 3.83:

Economical	Ticket price($)	Associated costs($
Ticket price($)	1	2.5
Associated costs($	0.4	1

Figure 3.83: Inner-dependency matrix for Economical cluster in choosing a flight

Decision maker values Ticket Price($) to be 2.5 more important than Associated Costs($). Economical cluster also features outer-dependency to Alternatives cluster i.e. each alternative is valued wrt to criteria inside Economical cluster:

Associated costs($	Swiss	easyJet	airberlin	British Airways	Brussels Airlines	AirFrance
Swiss	1	4	4	1	4	1
easyJet	0.25	1	1	0.25	1	0.25
airberlin	0.25	1	1	0.25	1	1
British Airways	1	4	4	1	4	1
Brussels Airlines	0.25	1	1	0.25	1	0.25
AirFrance	1	4	1	1	4	1

Associated costs($	Safety	Comfort
Safety	1	1
Comfort	1	1

Figure 3.84: Associated Costs matrix for choosing a flight

Ticket price($)	Swiss	easyJet	airberlin	British Airways	Brussels Airlines	AirFrance
Swiss	1	0.5988372093	1.81395348837	1.46511627907	1.53488372093	1.16860465116
easyJet	1.6699029126278	1	3.02912621359	2.44660194175	2.56310679612	1.95145631068
airberlin	0.5512820512826	0.3301282051284	1	0.80769230769	0.84615384615	0.64423076923
British Airways	0.6825396825395	0.4087301587297	1.2380952380987	1	1.04761904762	0.79761904761
Brussels Airlines	0.6515151515152	0.3901515151509	1.1818181818235	0.9545454545445	1	0.76136363636
AirFrance	0.8557213930368	0.5124378109451	1.5522388059720	1.2537313432978	1.3134328358271	1

Ticket price($)	Safety	Comfort
Safety	1	0.3333333333333
Comfort	3	1

Figure 3.85: Ticket Price matrix for choosing a flight

Also, as shown on above figures, Economical cluster has an outer-dependency to Other cluster. This relationship captures the link between Ticket Price($) and Other cluster's criteria, Comfort and Safety. To be more specific, decision maker attempted to represent that Ticket Price($) contributes 3 times more towards the Comfort compared to Safety. However, Associated Costs($) criterion has no impact on Other cluster's criteria.
Next cluster to be taken into consideration is Other cluster. It has very simple structure and features outer-dependencies to Alternatives cluster only.
Corresponding dependency matrices are given below:

Safety	Swiss	easyJet	airberlin	British Airways	Brussels Airlines	AirFrance
Swiss	1	5	6	2	3	2
easyJet	0.2	1	1.25	0.3333333333333	0.5	0.25
airberlin	0.1666666666666	0.8	1	0.3333333333333	0.5	0.25
British Airways	0.5	3	3	1	2	1
Brussels Airlines	0.3333333333333	2	2	0.5	1	0.5
AirFrance	0.5	4	4	1	2	1

Figure 3.86: Safety matrix for choosing a flight

Comfort	Swiss	easyJet	airberlin	British Airways	Brussels Airlines	AirFrance
Swiss	1	3	3	0.5	1	0.5
easyJet	0.3333333333333	1	1	0.1666666666666	0.3333333333333	0.25
airberlin	0.3333333333333	1	1	0.1666666666666	0.3333333333333	0.25
British Airways	2	6	6	1	2	1.3333333333333
Brussels Airlines	1	3	3	0.5	1	0.6666666666666
AirFrance	2	4	4	0.75	1.5	1

Figure 3.87: Comfort matrix for choosing a flight

Last cluster in ANP network, Airport, features two sub-clusters. Sub-cluster Facilities represents facilities at both, arrival and departure, airports. Sub-cluster Location represents location of both, arrival and departure, airports. Each sub-cluster features a self-loop (not visible on the diagram) to capture inner-dependencies. Outer cluster, Airport, has also a self-loop to establish relative importance of Location and Facilities sub-clusters wrt to goal.
Corresponding matrices are shown below:

Airport	Facilities	Location
Facilities	1	0.3333333333333
Location	3	1

Figure 3.88: Inner-dependency matrix for Airport cluster in choosing a flight

Location	Arrival	Departure
Arrival	1	0.5
Departure	2	1

Figure 3.89: Inner-dependency matrix for Location sub-cluster in choosing a flight

Facilities	Departure	Arrival
Departure	1	5
Arrival	0.2	1

Figure 3.90: Inner-dependency matrix for Facilities sub-cluster in choosing a flight

In addition to that, Airport cluster features two outer-dependencies: Airport-to-Economical and Airport-to-Alternatives.
Airport-to-Economical allows for establishing a relationship between Associated Costs($) and Location sub-cluster. For example, airport located far away will impact Associated Costs($) e.g. more expensive train ticket or longer taxi drive.
Airport-to-Alternatives is a simple type Criteria-To-Alternative relationship which allows to value alternatives wrt to criteria inside Airport cluster.
All relevant matrices are shown on Figure 3.91, 3.92, 3.93, 3.94:

Arrival	Swiss	easyJet	airberlin	British Airways	Brussels Airlines	AirFrance
Swiss	1	1	1	1	1	1
easyJet	1	1	1	1	1	1
airberlin	1	1	1	1	1	1
British Airways	1	1	1	1	1	1
Brussels Airlines	1	1	1	1	1	1
AirFrance	1	1	1	1	1	1

Arrival	Ticket price($)	Associated costs($
Ticket price($)	1	1
Associated costs($	1	1

Figure 3.91: Arrival matrix from Facilities sub-cluster for choosing a flight

Departure	Swiss	easyJet	airberlin	British Airways	Brussels Airlines	AirFrance
Swiss	1	3	3	0.5	3	1
easyJet	0.33333333333333	1	1	0.25	1	0.33333333333333
airberlin	0.33333333333333	1	1	0.25	1	0.33333333333333
British Airways	2	4	4	1	4	2
Brussels Airlines	0.33333333333333	1	1	0.25	1	0.33333333333333
AirFrance	1	3	3	0.5	3	1

Departure	Ticket price($)	Associated costs($
Ticket price($)	1	1
Associated costs($	1	1

Figure 3.92: Departure matrix from Facilities sub-cluster for choosing a flight

Arrival	Swiss	easyJet	airberlin	British Airways	Brussels Airlines	AirFrance
Swiss	1	1	1	1	1	1
easyJet	1	1	1	1	1	1
airberlin	1	1	1	1	1	1
British Airways	1	1	1	1	1	1
Brussels Airlines	1	1	1	1	1	1
AirFrance	1	1	1	1	1	1

Arrival	Ticket price($)	Associated costs($
Ticket price($)	1	2
Associated costs($	0.5	1

Figure 3.93: Arrival matrix from Location sub-cluster for choosing a flight

Departure	Swiss	easyJet	airberlin	British Airways	Brussels Airlines	AirFrance
Swiss	1	4	4	1	4	1
easyJet	0.25	1	1	0.25	1	0.25
airberlin	0.25	1	1	0.25	1	0.25
British Airways	1	4	4	1	4	1
Brussels Airlines	0.25	1	1	0.25	1	0.25
AirFrance	1	4	4	1	4	1

Departure	Ticket price($)	Associated costs($
Ticket price($)	1	3
Associated costs($	0.33333333333333	1

Figure 3.94: Departure matrix from Location sub-cluster for choosing a flight

Finally, inter-cluster dependency matrix is also modified to highlight priority of certain cluster over others:

Cluster Matrix	Alternatives	Economical	Airport	Other
Alternatives	1	1	1	1
Economical	1	1	3	2
Airport	1	0.33333333333333	1	0.5
Other	1	0.5	2	1

Figure 3.95: Inter-cluster matrix for choosing a flight

ANP result:

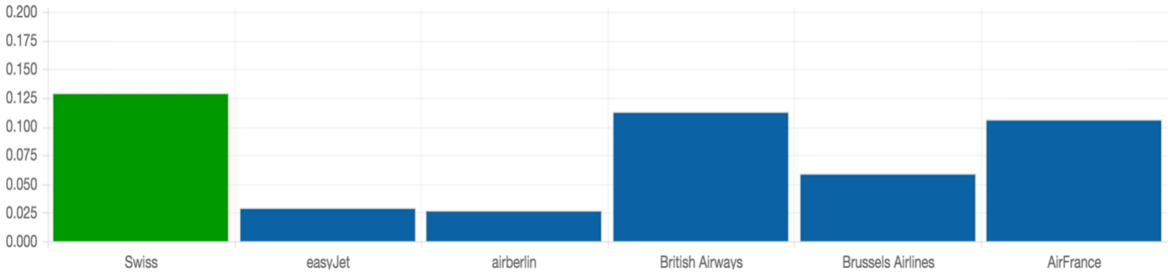


Figure 3.96: ANP result for choosing a flight

Both, TOPSIS and ANP, suggested Swiss as the best alternative. Hence, there is no need to consider trade-offs.

Chapter 4

Summary and Conclusions

From implementation-side, TrAdeCIS front-end was tested and significantly improved. This was achieved by applying patches to project's HTML, CSS and Javascript files.
7 real-world test cases of different complexity have been collected. Each test case is unique not only in terms of the underlying data, but also attempts to test different parts of ANP and TOPSIS implementation. In addition to that, I sincerely hope that collected test cases would assist newcomers to better and faster understand key concepts behind MCDA algorithms, namely, TOPSIS and ANP. I haven't managed to find myself any online resource that would explain ANP usage in a concrete context clearly stating real-world context behind ANP network relationships.
Finally, there are few suggestions for future researchers on improving TrAdeCIS.
During inputting test-cases I have found that the application doesn't have a feature to support saving intermediate decision state. In my opinion, such a feature would be a very useful addition to TrAdeCIS because it will allow to create decision step-by-step in time, switch back and forth between ANP and TOPSIS parts of decision and modify the data. Furthermore, it will provide a protection against accidental data losses due to bad network connection or accidental closing of the browser link.
Rewriting TrAdeCIS using latest web-development technologies and frameworks would make the application more responsive and robust. There are plenty of new technology such as ReactJS, AngularJS which allow to render web pages much quicker.
Performance testing is a key to well-behaved system. Testing TrAdeCIS with a cases of large complexity including multiple hundreds of criteria and alternative may cause unexpected errors. How many users can application support at the same time, how much processing power delegate for every user, is it possible for a huge decision to cause a database error - these are only some of the questions that should be considered in testing TrAdeCIS behavior.
Finally, security side of the question is another crucial component to successful web application. For example, how would the system protect against an attacker trying to acquire all system resources e.g. by running very complex decision or having multiple sessions running in parallel, and causing DDOS attack. Or, does the application feature any mechanisms to prevent SQL injection and Cross-Site scripting attacks. Security of the system determines number of users that will trust your system.