SELECTION OF PHOTOVOLTAIC SOLAR POWER PLANT PROJECTS USING ANP

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ABSTRACT

This paper presents an analysis to simplify a complex model, based on the Analytic Network Process (ANP); to select photovoltaic (PV) solar power projects. These projects follow a long management and execution process from plant site selection to plant start-up. As a consequence, there are many risks of time delays and even of project stoppage. In a previous work a top manager of an important Spanish company decided on the best PV project (from four alternative projects) to invest based on risk minimization, using a complex ANP model (54 elements grouped into different clusters). This model needs to be simplified in order to solve similar selection problems in future.

To identify which risks have to be eliminated from the original model is a difficult task. In this work two ways for doing this identification are proposed: in the fist way we select the 25 more important risks obtained by the original ANP model; in the second way we asked the decision maker to select the 25 risks that he considers have to be included in the future selection problems. The differences between both models are analyzed.

In both cases the original ANP model, including its influences between elements of the network, has been simplified using Superdecisions software.

Keywords: Analytic network process (ANP), project selection, photovoltaic (PV) solar power projects

1. Introduction

Spain has very good conditions for the development of photovoltaic solar power systems due mainly to the high mean daily radiation and the high number of sunny days in most parts of the country. For this reason, the Administration and companies working in the sector are developing policies and investing in photovoltaic solar power systems (Salas and Olias, 2008).

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The present paper analyzes the problem for the top manager, acting as *Decision Maker* (DM), of an important solar power investment company to establish a priority order among different projects for the development of a photovoltaic solar power plant. The decision problem presented here is highly complex because in addition to economic profitability, the risks involved in the development, construction, execution and maintenance of the plant are relevant factors in the decision making process. Investment companies that execute the project and further exploit the installations cannot have their resources inactive while waiting for the corresponding construction approval and execution permits, which may get delayed, or depend on long negotiations with the power supply company.

In a previous work the DM, assisted by the research team of the Department of Engineering Projects of the Polytechnic University of Valencia, playing the role of *Analysis Team* (AT), solved the following decision-making problem: "*Given a number of photovoltaic power investment projects that are known to be profitable for the company, establish project priority based on project risk levels and execution time delays"*. Four specific projects were prioritized and fifty risks were identified. These risks were grouped into clusters and, following the ANP method, the influences between elements and between clusters were identified and prioritized. In the following we will refer to this model as *complex model*.

The problem raised by the DM was that this model was too complex to use in future similar decision making problems and he asked the AT to simplify it. The way to do this is not an easy task. The results of the complex model showed us the prioritization between alternatives and the weights of the risks but these weights depend on the specific projects that have been considered. In this work two ways for doing this identification are proposed: in the fist way we select the 25 more important risks obtained by the original ANP model; in the second way we asked the decision maker to select the 25 risks that he considers have to be included in the future selection problems.

The rest of the paper is organized as follows. Firstly, Section 2 introduces the complex model and presents the main results. Section 3 describes the simplification process and Section 4 presents the main conclusions drawn from this research and future works.

2. Description of the complex model

The steps of the decision-making process were the following:

i. Analysis of the project stages involved in the development of a PV solar power plant.
ii. Risk Identification and classification.
iii. Specification of the Project portfolio.
iv. ANP modelling of the decision-making problem.
v. ANP prioritization and conclusions.

At the first step the process of developing a photovoltaic solar power plant was analyzed from the selection of the best plant site to the execution, exploitation and maintenance of the plant. This analysis allowed the DM to identify project delay or stoppage risks for each stage of the process. At step ii) fifty risks were identified and grouped into eleven clusters: political, technical associated with plant site, technical associated with technology, economic associated with plant exploitation, economic associated with the obtaining of the plant start-up permits, economic associated with plant site, economic associated with technology, macroeconomic, time delays, legal and social risks.

In step iii) the DM identified the projects that were used as alternatives in the decision process. Project selection was based on criteria of economic profitability, and technical and environmental feasibility. Four projects with different characteristics and plant location were finally selected.

The ANP model of the decision making process was built in step iv) following the main steps of this method (Saaty, 2001). The decision model was built with the support of Super Decisions v1.6.0. software (www.superdecisions.com). The results obtained are shown in Tables 1 and Table 2 (in Table 1 only the first twenty five classified weights are included ordered by preference/influence).

	Risks	ANP complex model influence	ANP complex model influence renormalized
C01	Changes in the energy policy	0.118	0.137
C50	Social consequences resulting from land acquisition	0.105	0.121
C40	Delays in the obtaining of the EIS	0.065	0.075
C47	Legislative changes in the EIS	0.063	0.073
C48	Thefts	0.063	0.073
C02	Local body Approval	0.060	0.069
C19	Revenue estimates based on effective solar radiation time	0.045	0.052
C39	Delays in the obtaining of the Local Body Approval	0.041	0.048
C30	Costs due to lack of consistency in solar tracker selection	0.031	0.035
C18	Performance losses	0.028	0.033
C22	Flood prevention works	0.026	0.030
C43	Changes in the general legislation	0.025	0.029
C38	Delays in the signature of the agreement with the Electricity supply company	0.023	0.026
C49	Vandalism	0.021	0.024
C37	Delays in the obtaining of the plant Start-up Act	0.016	0.019
C15	Plant operation costs	0.016	0.019
C42	Changes in the specific legislation	0.015	0.018
C21	Earthworks resources	0.014	0.017
C34	Changes in energy prices	0.014	0.016
C46	Obtaining of the Registration in the Register of Production Facilities in special Regime	0.013	0.015
C03	Obtaining of the Construction License	0.013	0.015
C16	Corrective maintenance costs	0.012	0.014
C45	Legislative changes in the Plant Start-up Act	0.012	0.014
C28	Costs due to wrong selection of PV cell	0.012	0.014
C09	Development of new PV solar power systems	0.011	0.013
	Total	0.862	1

Table 1.- First twenty five risks in the ANP complex model

A3	0.144
A4	0.159
A1	0.285
A2	0.412

Table 2.- Alternative ranking in the ANP complex model

Let's now mention an important consideration that affected the whole decision analysis process: although the main goal of the problem was *to select the project with the lowest risk*, when formulating the comparison matrices to weigh the risks according to Saaty's 1-9 scale, the *highest* weight was obtained by the risk with the *highest* score; i.e. when comparing the importance of two risks, it was easier for the DM to score 9 a risk that was extremely more important than another risk with which it was compared. In this sense, for the risk-based assessment of the alternatives, the DM thought it better to consider a higher risk alternative more important than the other alternatives under comparison. And this is the reason why the alternative with a *higher* score also obtained a *higher* risk value. Thus, in the results of ANP the alternative with the highest score is also the alternative with the highest risk value. This is why the formulation of the main goal of the problem states "to minimize risks". However, for the final decision and taking into consideration all risks, the alternative with *the lowest score* is considered a better option, and therefore the project globally assessed as the alternative with the lowest risk value is the alternative finally selected as the best option.

3. Simplification process

The DM was pleased with the results of the complex model. However, he realized how difficult it was to apply this model to future similar cases. So he asked the AT to simplify this complex model. The main problem was to select the main risks to take into account in future prioritizations. The AT observed that the twenty five more influential risks account for 86.2% of the total weight. The AT considered better to build up a new model with twenty five risks.

The second problem was which twenty five risks to select. At this stage two different ways to do this selection seemed reasonable. The first one was to select directly the first twenty five more influential risks obtained in the complex model (Table 3). The second one was to ask the DM to select the twenty five risks to be selected in future similar decision making problems (Table 4).

POLITICAL	C01	Changes in the energy policy
	C02	Obtaining of the Local body Approval
	C03	Obtaining of the Construction License
TECHNICAL ASSOCIATED WITH TECHNOLOGY	C09	Development of new PV solar power systems
ECONOMIC ASSOCIATED WITH PLANT EXPLOITATION	C15	Plant operation costs
	C16	Corrective maintenance costs
	C18	Performance losses
ECONOMICS ASSOCIATED WITH PLANT SITE	C19	Revenue estimation based on effective solar radiation time
	C21	Earthworks resources
	C22	Flood prevention works
ECONOMIC ASSOCIATED WITH TECHNOLOGY	C28	Costs due to wrong selection of PV cell
	C30	Costs due to lack of consistency in solar tracker selection
MACROECONOMIC	C34	Changes in energy prices
TIME DELAYS	C37	Delays in the obtaining of the plant Start-up Act
	C38	Delays in the signature of the agreement with the Electricity supply company
	C39	Delays in the obtaining of the Local Body Approval
	C40	Delays in the obtaining of the EIS
LEGAL	C42	Changes in the specific legislation
	C43	Changes in the general legislation
	C45	Legislative changes in the Plant Start-up Act
	C46	Obtaining of the Registration in the Register of Production Facilities in special Regime
	C47	Legislative changes in the EIS
SOCIAL	C48	Thefts
	C49	Vandalism
	C50	Social consequences resulting from land acquisition

Table 3.- First twenty five risks from the ANP complex model

POLITICAL	C01	Changes in the energy policy
	C02	Obtaining of the Local body Approval
	C03	Obtaining of the Construction License
TECHNICAL ASSOCIATED WITH PLANT SITE	C04	Technological adequacy to climate change
TECHNICAL ASSOCIATED WITH TECHNOLOGY	C09	Development of new PV solar power systems
	C13	Connection to the electric grid
	C14	Possibility of alternative power generation systems
ECONOMIC ASSOCIATED WITH PLANT EXPLOITATION	C15	Plant operation costs
ECONOMIC ASSOCIATED WITH THE OBTAINING OF THE PLANT START-UP PERMITS	C24	Costs of connection to electric grid
	C26	Possibility of constructing the power connection line
MACROECONOMIC	C31	Obtaining of bank financing
	C33	Changes in the price of money
	C34	Changes in energy prices
TIME DELAYS	C35	Delays in the construction of the power connection line
	C36	Delays in the obtaining of the administration approval for the construction of the line
	C37	Delays in the obtaining of the plant Start-up Act
	C39	Delays in the obtaining of the Local Body Approval
	C40	Delays in the obtaining of the EIS
	C41	Delays in the obtaining of the construction license
LEGAL	C42	Changes in the specific legislation
	C44	Legislative changes in the Administrative Authorization of the power distribution line
	C45	Legislative changes in the Plant Start-up Act
	C46	Obtaining of the Registration in the Register of Production Facilities in special Regime
	C47	Legislative changes in the EIS
SOCIAL	C50	Social consequences resulting from land acquisition

Table 4.- Twenty five risks chosen by the DM

4. Simplified models and results

Both models have to preserve current cluster structure and the influences established in the complex model. If this structure changes the judgments made by DM should be reconsidered. The AT simplified the complex model with the support of Superdecisions software. Figure 1 and Figure 2 show these two simplified models. Table 5 shows the comparative results and Table 6 shows Hadamard’s compatibility index.

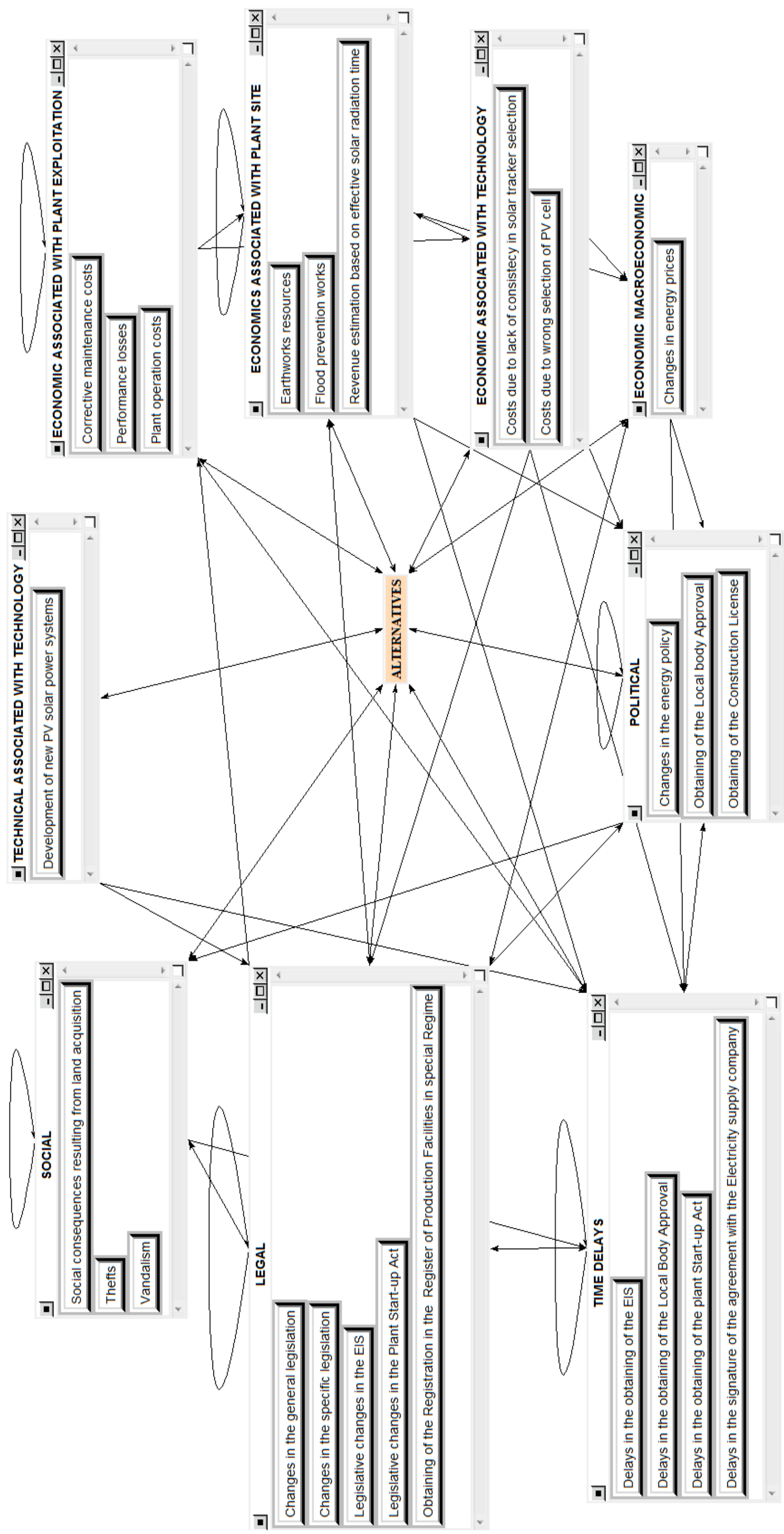

Figure 1.- Simplified model with twenty five risks selected by the ANP complex model

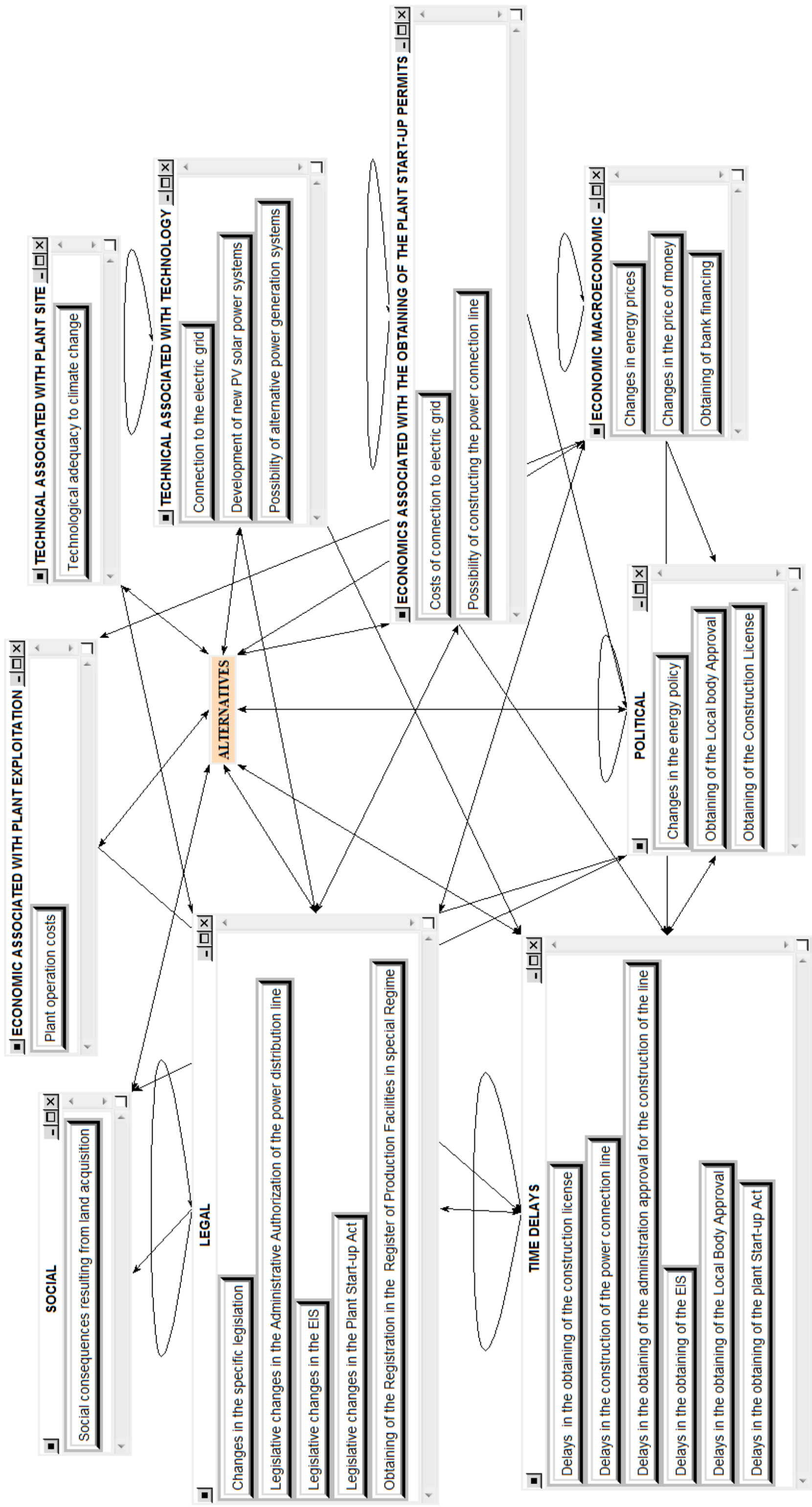

Figure 2.- Simplified model with twenty five risks selected by the DM

a)

	A1	A2	A3	A4	C01	C02	C03	C09	C15	C16	C18	C19	C21	C22	C28	C30	C34	C37	C38	C39	C40	C42	C43	C45	C46	C47	C48	C49	C50
A1					0,2689	0,0205	0,0124	0,1229	0,1681	0,1873	0,1476	0,0356	0,0495	0,2220	0,0955	0,1667	0,0633	0,0148	0,0063	0,0075	0,0141	0,0086	0,0169	0,0079	0,0115	0,0092	0,0979	0,0918	0,1004
A2					0,4914	0,0323	0,0292	0,0380	0,2778	0,3097	0,2440	0,0613	0,1185	0,0584	0,1365	0,0514	0,1046	0,0148	0,0290	0,0252	0,0270	0,0143	0,0279	0,0131	0,0178	0,0161	0,1497	0,1518	0,1660
A3					0,1460	0,0025	0,0021	0,0380	0,0297	0,0315	0,0248	0,3624	0,0150	0,0157	0,0146	0,0156	0,0106	0,0049	0,0022	0,0028	0,0018	0,0015	0,0028	0,0013	0,0019	0,0013	0,0161	0,0154	0,0169
A4					0,0937	0,0077	0,0104	0,0355	0,0640	0,0772	0,0608	0,1446	0,1658	0,1121	0,0357	0,0486	0,0261	0,0148	0,0117	0,0139	0,0064	0,0033	0,0070	0,0033	0,0048	0,0046	0,0332	0,0378	0,0414
C01	0,0833	0,0525	0,0833	0,0304								0,2057			0,1043	0,1043	0,0834		0,3180			0,4159	0,8190	0,3845	0,5406	0,4679			
C02	0,0525	0,0833	0,0525	0,1106			0,1417											0,0795		0,2650	0,3180								
C03	0,0220	0,0220	0,0220	0,0167														0,2385		0,0530									
C09	0,0603	0,0603	0,0603	0,0603																									
C15	0,0536	0,0536	0,0536	0,0536							0,0530																		
C16	0,0258	0,0258	0,0258	0,0258							0,1591																		
C18	0,1115	0,1114	0,1114	0,1114																					0,0999				
C19	0,0313	0,0313	0,1657	0,0313									0,4613	0,5401	0,1744	0,1744						0,0470			0,0610				
C21	0,0651	0,0651	0,0331	0,0651																									
C22	0,1355	0,1355	0,0331	0,1355					0,1093																				
C28	0,0197	0,0247	0,0823	0,0197					0,0464	0,0521	0,0411																		
C30	0,0790	0,0741	0,0165	0,0790					0,2322	0,2607	0,2054																		
C34	0,0183	0,0183	0,0183	0,0183								0,0764	0,0441	0,0516	0,0414	0,0414						0,0642	0,1264						
C37	0,0072	0,0073	0,0387	0,0073					0,0725	0,0814	0,0641						0,0221					0,0121					0,0856	0,0856	
C38	0,0358	0,0340	0,0501	0,0340				0,1516							0,0869		0,1102	0,0264		0,0237		0,0676		0,0581					
C39	0,0124	0,0132	0,0176	0,0132		0,2846	0,2443	0,3153					0,0292		0,0352	0,0561	0,1102	0,0150			0,1185	0,0387		0,0236					
C40	0,0621	0,0630	0,0111	0,0630		0,0949	0,0814	0,2186					0,1167		0,2143	0,2804	0,3305	0,0771	0,1185	0,0948		0,1250		0,1433		0,2738			
C42	0,0062	0,0062	0,0122	0,0061				0,0468				0,0997			0,0447	0,0447	0,0695							0,0622	0,2187				
C43	0,0011	0,0011	0,0024	0,0011				0,0108				0,0143			0,0050	0,0050	0,0695					0,2019		0,1244	0,0437	0,2271			
C45	0,0034	0,0034	0,0061	0,0036														0,5142											
C46	0,0018	0,0018	0,0037	0,0017				0,0225							0,0115	0,0115			0,5142										
C47	0,0130	0,0130	0,0010	0,0129																0,5142	0,5142								
C48	0,0097	0,0097	0,0331	0,0097																				0,0891					0,5628
C49	0,0331	0,0331	0,0331	0,0331																				0,0891					0,1126
C50	0,0565	0,0565	0,0331	0,0565		0,5575	0,4785																				0,6175	0,6175	

b)

	A1	A2	A3	A4	C01	C02	C03	C04	C09	C13	C14	C15	C24	C26	C31	C33	C34	C35	C36	C37	C39	C40	C41	C42	C44	C45	C46	C47	C50
A1					0,2689	0,0205	0,0124	0,2188	0,0621	0,023	0,0197	0,2336	0,0585	0,089	0,0313	0,064	0,0311	0,0107	0,0126	0,0148	0,0075	0,0141	0,0069	0,0122	0,0071	0,0101	0,0135	0,0125	0,3093
A2					0,4914	0,0323	0,0292	0,2188	0,0192	0,1066	0,0592	0,3862	0,3299	0,2922	0,0318	0,1057	0,0515	0,0292	0,0291	0,0148	0,0252	0,027	0,0276	0,0202	0,0153	0,0166	0,0209	0,0218	0,5113
A3					0,146	0,0025	0,0021	0,2188	0,0192	0,008	0,0197	0,0412	0,0301	0,0238	0,0041	0,0108	0,0052	0,002	0,002	0,0049	0,0028	0,0018	0,0018	0,0022	0,0013	0,0017	0,0022	0,0018	0,052
A4					0,0937	0,0077	0,0104	0,2188	0,0179	0,0362	0,0197	0,089	0,1387	0,0681	0,0146	0,0264	0,0128	0,0074	0,0057	0,0148	0,0139	0,0064	0,013	0,0046	0,0037	0,0041	0,0057	0,0062	0,1275
C01	0,0954	0,0601	0,0954	0,0349										0,1509	0,0201	0,1297	0,0631	0,318	0,318					0,6118	0,4291	0,5077	0,6592	0,6592	
C02	0,0601	0,0954	0,0601	0,1267			0,1417								0,0169					0,0795	0,265	0,318	0,2385						
C03	0,0252	0,0252	0,0252	0,0192											0,0143					0,2385	0,053		0,0795						
C04	0,1198	0,1198	0,1198	0,1198																									
C09	0,0239	0,0246	0,0634	0,0254							0,318																		
C13	0,0881	0,0867	0,0168	0,0852																									
C14	0,0081	0,0087	0,0399	0,0095					0,318																				
C15	0,2101	0,2101	0,2101	0,2101											0,1862														
C24	0,0172	0,0216	0,0647	0,0216										0,0669											0,0254				
C26	0,069	0,0647	0,0216	0,0647									0,0788												0,1269				
C31	0,0019	0,0017	0,0019	0,0017																									
C33	0,0045	0,0048	0,0045	0,0048											0,0691		0,4244							0,0072					
C34	0,0141	0,014	0,0141	0,014											0,2763									0,0647					
C35	0,0086	0,0084	0,015	0,008						0,0881	0,0501					0,0465	0,0123			0,0052				0,0197	0,0204	0,0299			
C36	0,0159	0,0139	0,0131	0,0148					0,0658	0,5152	0,0672		0,0568	0,0449	0,0267	0,0726	0,0406	0,1185		0,015				0,0392	0,1238	0,05			
C37	0,0066	0,0072	0,0231	0,0071							0,0187	0,25				0,0269	0,023							0,0115					
C39	0,024	0,0243	0,0169	0,0241		0,2846	0,2119		0,2375		0,1132		0,0265	0,0221	0,0779	0,1922	0,077			0,0313		0,1185	0,0296	0,068		0,0171			
C40	0,0503	0,0514	0,0103	0,0511		0,0949	0,0413		0,1722		0,2358		0,1638	0,1419	0,1441	0,2986	0,159		0,1185	0,058	0,1053		0,0888	0,1272		0,1244		0,2986	
C41	0,0043	0,0044	0,0312	0,0044			0,0725		0,0388	0,1507	0,0292		0,0108	0,0101	0,014	0,0269	0,0109			0,0089	0,0132			0,0115	0,0502	0,0085			
C42	0,0117	0,0117	0,0215	0,0112				0,125	0,037		0,0411				0,0724		0,089									0,0328	0,2986		
C44	0,0048	0,0054	0,0108	0,0033						0,0158			0,1061	0,015				0,1285		0,0857						0,1971			
C45	0,0043	0,004	0,0072	0,0062															0,5142	0,4285									
C46	0,0021	0,0021	0,0043	0,002					0,0123	0,0048	0,0082																		
C47	0,0226	0,0224	0,0018	0,0227						0,0517				0,0751				0,3857			0,5142	0,5142	0,5142						
C50	0,1075	0,1075	0,1075	0,1075		0,5575	0,4785																		0,1968				

Table 6.- Weighted supermatrix: a) 25 ANP, b) 25 DM

25 ANP		ANP DM		ANP COMPLEX	
A4	0.145	0.106	A3	0.144	A3
A3	0.146	0.133	A4	0.159	A4
A1	0.288	0.278	A1	0.285	A1
A2	0.421	0.483	A2	0.412	A2
C50	0.122	0.145	C01	0.137	C01
C01	0.116	0.107	C50	0.121	C50
C40	0.083	0.100	C47	0.075	C40
C48	0.074	0.091	C40	0.073	C47
C47	0.071	0.089	C02	0.073	C48
C02	0.066	0.087	C15	0.069	C02
C19	0.058	0.060	C39	0.052	C19
C39	0.049	0.050	C04	0.048	C39
C22	0.041	0.033	C13	0.035	C30
C30	0.037	0.033	C36	0.033	C18
C18	0.037	0.030	C45	0.030	C22
C49	0.025	0.028	C26	0.029	C43
C43	0.024	0.026	C37	0.026	C38
C38	0.021	0.021	C03	0.024	C49
C34	0.019	0.015	C09	0.019	C37
C21	0.019	0.015	C42	0.019	C15
C09	0.019	0.014	C44	0.018	C42
C15	0.019	0.013	C41	0.017	C21
C37	0.018	0.013	C24	0.016	C34
C42	0.016	0.010	C14	0.015	C46
C16	0.014	0.009	C35	0.015	C03
C03	0.014	0.007	C34	0.014	C16
C28	0.013	0.005	C33	0.014	C45
C46	0.013	0.001	C46	0.014	C28
C45	0.010	0.001	C31	0.013	C09

Table 5.- Results

	ANP DM	25 ANP
ANP Complex	1.03058	1.00218
ANP DM	-	1.02703

Table 6.- Hadamard’s compatibility index

The prioritization of the alternatives gives similar results in the ANP complex and 25 DM models (compatibility index = 1.002). The elimination of the less influential criteria hardly affects the results in the complex model. Although a change in the position of alternatives A3 and A4 can be observed, the differences in the priorities of these two alternatives are meaningless. In the ANP complex model A3 obtains better results than A4, and in the 25 ANP model both alternatives get similar values.

When comparing alternative prioritization in the ANP DM model and in the other two models, alternative A3 gets better values in the ANP DM model. The compatibility index is acceptable (1.030 in the comparison between the ANP DM model and the ANP complex model, and 0.027 in the comparison between the ANP DM model and the 25 ANP model). Note that the three models show similar results.

As regards criteria weights, similar weight values are obtained in the ANP complex and 25 ANP models. The elimination of the 25 less influential criteria hardly affects these results. However, the comparison of the weights in these two models with the weights of the ANP DM model reveals significant differences, as some criteria change their position in the ranking order.

5. Conclusions

The process of model simplification is not an easy task. Although the elimination of the less influential criteria may seem the easiest procedure for model simplification and in the present case study provides a better compatibility index, this method has the drawback of being based on the selection of the most influential criteria for a particular situation. However, the initial idea was to develop a model of criteria and influences applicable to similar decision problems.

Based on the findings of the present analysis, we recommend asking the DM in each new decision problem about which criteria should be included in or removed from the original model, and using the complex model as a compatibility test for the simplified model. The results suggest that although the compatibility index values are worse when using the criteria selected by the DM, the compatibility index obtained is acceptable. The DM possesses a deep understanding of the problem and therefore his criteria selection includes the most influential factors commonly found in this type of decision problems.

The structure of the clusters was not modified as it had involved asking the DM again about the selected criteria. If, for example, the economic and technical criteria had been unified, the new influences over other elements would have had to be calculated. And this would have involved re-constructing part of the process

The general conclusion that can be drawn from the present study is that in ANP the identification and clustering of criteria is a key step that affects the final results obtained in the process. Therefore, it is essential to perform this step carefully and that the DM applies his knowledge and experience to the identification of the criteria to take into account in the decision problem

6 References

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