SELECTION OF RAIL IMPROVEMENT PROJECTS USING THE ANALYTIC NETWORK PROCESS (ANP)

J. Montesinos-Valera. P. Aragonés-Beltrán*. J.P. Pastor-Ferrando.
Department of Engineering Projects
Universidad Politécnica de Valencia
Camino de Vera s/n
46022 Valencia (Spain)

ABSTRACT

In this article the application of the Analytic Network Process (ANP) to establish priorities among the portfolio of rail infrastructure maintenance, rehabilitation and improvement projects in the area of Valencia (Spain) is presented. The problem is complex because of the large number and variety of projects to be considered and the great number of criteria that must be taken into account in the decision analysis process.
The present work is a continuation of a previous research based on the AHP model. The present study analyzes the different priority values of a particular group of projects obtained in ANP and AHP as well as changes in the weights of the criteria and the possibility of eliminating minor criteria from the model for the sake of simplicity.

Keywords: Maintenance, Rehabilitation and Improvement of railway lines; Analytic Network Process

1. Introduction

The construction of railway infrastructure networks requires heavy investment and long execution times and life cycles. Maintenance, rehabilitation and improvement (MR&I) of railway lines are essential to maintaining railway infrastructures in good condition and to adapt them to environmental changes and new operating conditions and needs. A critical issue for public infrastructure managers and planners is the effective allocation of the scarce resources available for MR&I of railway infrastructures.
Every year the Manager of a rail network area (Local Manager) is faced with different MR&I needs. This is materialized in projects to be executed with different levels of urgency, different levels of investment and different improvement measures and action plans on the railway network. Therefore, the Manager has a portfolio of MR&I projects and a limited budget. The problem is that of selecting the MR&I projects that should be executed first. It is a complex problem with a large number of possible actions and criteria to take into consideration. In this paper, the problem is addressed as a multi-criteria decision making (MCDM) problem in which a method is designed using ANP (Saaty. 2001) to help the manager to prioritize the MR&I projects.
AHP and ANP have been used in the field of railway management and other similar projects, such as route selection for a pipeline (Thomaidis et Mavrakis, 2006), selection of major international rail projects (Tsamboulas, 2007), selection of urban tram routes (Gerçek et al, 2004) or prioritization of railways lines to reconstruct (Baric et al. 2006)
The method is applied to a case study described below. The present study presents the generalization of a cost-benefit based ANP model developed from an initial AHP-based analysis. In this paper only the alternatives previously selected as being representative of different types of possible actions, namely 24 alternatives, are analyzed.

* Corresponding author

2. Case study

ADIF (Railway Infrastructure Manager) is the manager of the Iberian gauge (1667 mm) railway system owned by the Spanish government. Among ADIF functions are the MR&I of rail infrastructure, which include the implementation of projects and preventive action plans. The rail network area selected for the case study is extensive including different train lines and infrastructures of all types, from non-electrified lines and mechanical-electrical signals to high-speed rail lines (220 km/h) with high performance and variable traffic levels. The lack of homogeneity among the possible actions makes the decision analysis much more complex. To facilitate the decision-making process, a detailed analysis of the possible actions and network sections was conducted to obtain homogeneous groups for further comparison.
The present study was carried out by the Local Manager of the Valencia Department along with one of the technicians of his Department (and coauthor of this paper) that acted as Decision Maker (DM) by consensus, assisted by two members of the research team of the Department of Engineering Projects of the Polytechnic University of Valencia, who played the role of Analysis Team (AT).
This work is the continuation of a previous one that used a hierarchical decision model (AHP) to establish priorities among the 418 improvement measures programmed for execution by the DM. A total of 24 criteria were identified and grouped for the assessment of the improvement actions using Ratings. The decision problem is also analyzed using a network model (ANP) because there are also influences among different criteria.

2.1 Identification and clustering of criteria.

At this stage the network of criteria and alternatives is identified to accurately reflect the influences among criteria. Due to the large number of alternatives the assessment technique used was the Rating method. For the analysis of the influences among criteria the DM decided to consider a control hierarchy with a cluster of Cost criteria and a cluster of Benefit criteria, both of which were given the same degree of importance, and to model each cluster as a subnet. The decision problem is "Given a particular railway infrastructure and a portfolio of MR&I projects, which are the priorities among the projects according to the identified criteria?. The analysis of the influence among criteria within each subnet was performed using a matrix of influence whose elements have value 1 if the row element has influence on the column element and otherwise value 0.

2.2 Identification of Categories.

Table 1 Criteria and Ratings Benefit Subnet

6 Economic efficiency criteria					
20 Cost of the action plans		21 Cost of follow-up actions		23 Amortization period	
Higher than 45 M€	0,421	Very High	1	Higher than 50 Years	0,139
Higher than 25 M€	0,070	High	0,468	Higher than 30 Years	0,266
Higher than 15 M€	0,735	Important	0,277	Higher than 10 Years	0,411
Higher than 7 M€	1	Negligible	0,082	Higher 20 years	0,383
Higher than 3 M€	0,421			Lower than 5 years	0,355
Lower than 3 M€	0,341				
22 Future operation costs		7 Rail line criteria (Type of track)			
Higher than 120 %	1	High performance primary lines			0,294
Higher than 110 %	0,670	Primary lines with level crossings			0,051
Higher than 100 %	0,563	Single-track primary lines			0,174
Higher than 80 %	0,261	High incidence primary lines			0,902
Higher than 60 %	0,132	Secondary lines			0,609
Higher than 50 %	0,073	Tracks for Technical servicing			1
11 Reduction in maintenance costs (This Criterion belongs to both Subnets)					
Higher than 50 %	1	Higher than 10%	0,428	Increase 10 %	0,113
Higher than 25%	0,895	Lower than 1%	0,218	Increase 20%	0,064

Tables 1 and Table 2 shows the criteria and categories used to assess the alternatives through a Rating system. The Ratings for each criterion were obtained by pairwise comparison, as defined by ANP.

Table 2 Criteria and Ratings Cost Subnet

1 Rail safety criteria.				*2 Performance efficiency criteria.*	
1 Reduction in the number of level crossings		2 Improvement of railroad crossing signs		5 Travel time Reduction	
Total.	1	Very High	1	Higher than 20 %	1
Significant	0,401	High	0,637	Higher than 10 %	0,509
Partial	0,172	Significant	0,222	Higher than 5 %	0,251
Indifferent	0,074	Negligible	0,112	Lower than 1 %	0,124
Increase	0,027	Reduction	0,060	Reduction	0,065
3 Improvement of driving support systems		4 Automatic control of routes and blocking systems		6 Critical Block Reduction	
Very High	1	Very High	1	Higher than 20 %	1
High	0,513	High	0,486	Higher than 10 %	0,517
Significant	0,254	Significant	0,493	Higher than 5 %	0,256
Negligible	0,145	Negligible	0,059	Lower than 1 %	0,164
Reduction	0,060			Reduction	0,057
3 Technical Efficiency Criteria				7 Increase in the number of lines	
9 Reduction in the number of incidences		10 Reduction in train delays		Higher than 100 %	1
Higher than 50 %	1	Higher than 50%	1	Higher than 50%	0,510
Higher than 20 %	0,509	Higher than 25 %	0,520	Higher than 20 %	0,251
Higher than 10 %	0,251	Higher than 10 %	0,572	Higher than 10 %	0,123
Lower than 1 %	0,123	Lower than 5 %	0,080	Reduction	0,065
Increase	0,065	Increase	0,059		
11 Reduction in maintenance costs (This Criterion belongs to both Subnets)				8 Improvement of operation systems	
Higher than 50 %	1	Lower than 1%	0,218	Very High	1
Higher than 25%	0,895	Increase 10 %	0,113	High	0,464
Higher than 10%	0,428	Increase 20%	0,064	Significant	0,208
				Negligible	0,098
4 Social criteria					
13 Improved connections between municipalities		14 Improvement of rail safety measures		15 Improvement of urban permeability	
Very High	1	Very High	1	Very High	1
High	0,510	High	0,510	High	0,510
Significant	0,251	Significant	0,251	Significant	0,251
Negligible	0,123	Negligible	0,123	Negligible	0,123
Reduction	0,065	Reduction	0,065	Reduction	0,065
5 Environmental Criteria					
16 Reduction of noise pollution		17 Energy efficiency Improvements		18 Environmental impact of the works	
Very High	1	Higher than 20 %	1	Very high	0,065
High	0,510	Higher than 10 %	0,510	High	0,123
Significant	0,251	Higher than 5 %	0,251	Medium	0,251
Negligible	0,123	Lower than 1 %	0,123	Low	0,510
Reduction	0,065	Reduction	0,065	Negligible	1
19 Reduction in operational EI					
Very high	1	Negligible	0,123		
High	0,510	Increase	0,065		
Significant	0,251				

2.3 Identification and assessment of the alternatives.

In the synthesis stage the ANP method was applied to the subnets. The DM made judgments using pairwise comparisons to construct the unweighted and weighted matrices. Then the DM evaluated the 24 alternatives for each criterion and gave them the corresponding rating. The resulting data were analyzed with Superdecisions software.

2.4 Results.

Table 3 shows the resulting values of the alternatives obtained in the ANP and AHP models. The best alternative is the alternative with the highest score. Table 4 shows the influence of each criterion on the other criteria in the Network model and the relative importance of each criterion over the others in the AHP model.

Table 3. Scoring and priority ranking of the alternatives in ANP and AHP.

ANP			AHP	
Name	**Ideals**	**Ranking**	**Ideals**	**Name**
32350G	**1**	1	**1**	**32350X**
33800P	**0.7604**	2	0.921883	31050X
31300D	**0.466181**	3	**0.843595**	**33800P**
32350X	**0.395194**	4	0.744125	31300X
32350A	**0.380199**	5	**0.666213**	**31300D**
31050X	0.337922	6	**0.652332**	**32350G**
31300X	0.316445	7	0.649123	30850R
30850R	0.233327	8	0.631141	32300V
30850O	0.223818	9	0.629941	32300U
30802X	0.197649	10	0.613798	30850O
31300N	0.197583	11	0.577203	33800D
32300U	0.183049	12	0.574993	31300N
32300V	0.176414	13	0.564718	30802X
33800D	0.167587	14	0.51007	33650H
33650H	0.158887	15	0.507649	30850J
33800K	0.145412	16	0.50657	30850I
30850I	0.140073	17	**0.492691**	**32350A**
30850J	0.140073	18	0.486926	31050B
31050B	0.130001	19	0.452659	32150Y
32150Y	0.112653	20	0.447606	33800K
31250M	0.103035	21	0.271652	33801L
31200H	0.080788	22	0.255119	31250M
33801L	0.061204	23	0.241832	31200H
33801H	0.054238	24	0.232454	33801H

2.5 Analysis of results

The resulting data present significant differences in the weights of the criteria. This is due to the fact that in AHP the results reflect the importance given by the decision maker to the individual criteria while ANP takes into consideration the influences among criteria.

The importance of the criteria in AHP is assigned by the DM based on his experience and knowledge. However, when considering the influences among the criteria, the degree of importance of the criteria changes. Criteria initially considered by the DM as very important are now considered less important. In general the criteria which combine improved functionality of the facilities gain influence over the criteria of indirect improvements, for example the automatic control of routes and blocking systems loses influence since its effect is transferred to other criteria such as reduction in the number of incidents, reduction of critical cant angles, increased capacity, etc.

With respect to the results obtained with AHP, the average change in the position of the alternatives is approximately 3.75. The alternatives with the lowest and highest weights occupy the same relative positions whereas the alternatives with medium weights experience changes in their positions.
The criteria with negligible influence in ANP could be neglected to simplify the evaluation of the improvement action plans. However, taking into account that the changes in the values given to the criteria by the decision maker could cause these factors to gain influence in the near future, their elimination from the model is not recommended, although another possibility would be to set values for a particular group of less-influential criteria in both AHP and ANP.

Table 4. Criteria influence and weights in ANP and AHP

Name	ANP	AHP	Name
24 Type of track	**0,3467**	0,1647	1 Reduction in the number of level crossings
11 Reduction in maintenance costs	**0,1218**	0,1197	3 Improvement of driving support systems
6 Critical block reduction	**0,1215**	0,1197	4 Automatic control of routes and blocking systems
5 Travel time reduction	**0,0786**	**0,1081**	**24 Type of track**
14 Improvement of rail safety measures	**0,0654**	**0,0939**	**5 Travel time reduction**
8 Improvement of operation systems	0,0577	0,0792	9 Reduction in number of incidences
1 Reduction in the number of level crossings	0,0538	**0,0516**	**6 Critical block reduction**
3 Improvement of driving support systems	0,0478	**0,0455**	**14 Improvement of rail safety measures**
4 Automatic control of routes and blocking systems	0,0423	0,0319	10 Reduction in train delays
22 Future operation costs	0,0314	0,0311	2 Improvement of railroad crossing signs
7 Increase in the number of lines	0,0141	0,0302	20 Cost of the action plans
2 Improvement of railroad crossing signs	0,0115	0,0296	7 Increase in the number of lines
10 Reduction in train delays	0,0053	0,0193	22 Future operation costs
9 Reduction in number of incidences	0,0017	0,0117	23 Amortization period
12 Improved diagnosis of equipment	0	0,0115	19 Reduction in operational EI
13 Improved connections between municipalities	0	0,0091	13 Improved connections between municipalities
15 Improvement of urban permeability	0	0,0091	15 Improvement of urban permeability
16 Reduction of noise pollution	0	0,0068	8 Improvement of operation systems
17 Energy efficiency Improvement	0	**0,0067**	**11 Reduction in maintenance costs**
18 Environmental impact of the works	0	0,006	12 Improved diagnosis of equipment
19 Reduction in operational EI	0	0,0047	16 Reduction of noise pollution
20 Cost of the action plans	0	0,0042	21 Cost of follow-up actions
21 Cost of follow-up actions	0	0,004	17 Energy efficiency Improvement
23 Amortization period	0	0,0013	18 Environmental impact of the works

3. Conclusions.

The present study, which is the continuation of a previous work based exclusively on AHP, presents a method to prioritize rail maintenance action plans using an ANP-based model to analyze influence among criteria.
The results show changes in priorities and the degree of importance / influence of the criteria. The results were relevant to the DM as the ANP analysis revealed a set of criteria with practically no influence. This raises the issue of whether these criteria should be eliminated from the model for the sake of simplicity, given that the Railway Company has to take a large number of alternatives into consideration every year.
The results were satisfactory for the DM because they matched his initial perception. After a more detailed analysis the DM concluded that the results were consistent with his experience and knowledge of

the problem. The DM also found the ANP-based analysis of influences to be useful, regardless of the results, as it made him reflect on the problem. The ANP method provided a similar ranking of projects, discarding less convenient projects in a much more efficient way and generating a similar list of key projects in both methods.

The high cost of rail MR&I action plans and the fact that the investments are publicly funded forcing the DM to budget as efficiently as possible. ANP allows the organization and systematic application of the information available to the decision maker. The railway network analyzed in the case study is valid for other local rail managers and rail departments where the decision maker will only have to re-calculate the pairwise comparisons to adjust the weights to the particular needs of his local area or to his personal perception of the problem.

In conclusion, most highly appreciated by the DM was having a tool that allowed for the systematic, strict and scientifically founded analysis of the data.

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