Use of Analytic Hierarchy Process (AHP) For Selection of Sustainable Rail Transport Proposal

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Abstract

With increasing greenhouse gas emissions, traffic congestion and oil prices, the concept of sustainability in transport infrastructure planning is receiving more and more attention. Decision and policy makers are urged to make decisions that are not only economically efficient but also sustainable. For that reason, new approaches are needed for comprehensive assessment that will take various economic, social, and environmental impacts into account. This paper introduces a decision support framework involving Analytic Hierarchy Process (AHP) to undertake a comprehensive sustainability assessment of a large transport infrastructure project. The AHP Framework is illustrated through a case study to find the best sustainable option for the construction of the Rail Baltica railway line through the Baltic countries and Poland. The AHP approach has been proved able to provide valid and useful decision support for making decisions that can contribute to promote sustainable transport development.

Keywords

Sustainability, Transport Investments, Analytic Hierarchy Process (AHP), Comprehensive Assessment, Strategic Impacts, Stakeholder Involvement.

I. Introduction

Transport is an essential component of today's life, allowing for mobility, providing a vital Lubricant to trade, and creating economic growth. Despite its unquestionable benefits, the negative external consequences of transport, such as greenhouse gas emissions, oil prices, congestion, accidents and a multitude of other factors must be dealt with [1]. This has led to the concept of sustainability becoming one of the main interests in transport planning over recent decades. The issue first came to the fore in 1987, when the question of sustainable development "meet the needs of the present without compromising the ability of future generations to meet their own needs" was raised by the 'World Commission on the Environment and Development' [2]. This question is, and will most likely remain, a central concern for policy-makers who want to create "a better future world". Of course, transport is only one element in sustainable development, albeit a very important one. When planning new large transport infrastructure, there are a number of issues which need to be taken into account because infrastructure tends to be long-lived and dedicated in its use. So it is important to make sound decisions that are both economically efficient and sustainable [3]. The dominant approach in project evaluation is cost-benefit analysis (CBA), which provides a systematic quantification and comparison of the various benefits and costs generated by a project [4]. Given the primary focus on economic issues, impacts which are indirect or more difficult to measure are very often ignored or at least not paid enough attention by decision-makers and policy-makers [5]. However, in many cases, these impacts can be very significant for long-term, strategic goals. With sustainability seen as increasingly important, decision-makers are being urged to adopt multi-disciplinary approaches that can systematically take into account all the various indirect and long-term impacts [6]. Even so, the question of sustainability does not necessarily influence the decision-making because greater importance is often given to the economic indicators rather than social and environmental concerns as the evaluation practice shows [5, 7-11] all focuses the importance of trade-offs between the traditional economics and other factors and the sustainability criteria in the decision-making process, in which they can be appropriately determined by the involvement of as many interested and affected stakeholders as possible. Comprehensive multi-disciplinary approaches should not only take the different factors and criteria into account, but should also integrate and appropriately weight these concerns in a process of selecting the best alternative.

This paper focuses on sustainable transport infrastructure planning, in which long-term economical, social and environmental impacts are taken into account for making decisions that contribute to "a better future world" from the sustainability point of view. To incorporate a variety of impacts for sustainable decision-making, we propose a decision support framework that applies AHP approach and adopts explicit sustainability strategy in a process of interaction with the different stakeholders at a decision conference. Such a strategy may be seen as useful because it allows the decision-makers to define the best alternative from the sustainability point of view. The evaluation is based on the criteria identified as relevant for the decision in hand and the viewpoints of all associated stakeholders on the explicit sustainability strategy. The decision support framework was applied to a case study of the Rail Baltica railway line through the Baltic countries and Poland, where the best sustainable option from a set of investment package proposals was found out. This demonstrated that the framework is a valid and useful tool for assessing decision problems in sustainable transport planning, where the rail case is just one example.

The paper is organized as follows. First the multi criteria decision framework is introduced and the principles behind the methods and techniques are described. Then the case study of the Rail Baltica project is presented with the results of the appraisal using the DSF. Finally, the results and the validity of the proposed decision support framework are discussed and conclusions are given including perspectives for future research.

II. The AHP Decision Support Framework

Decision-making in transport planning is often a complex process due to the constraints, multiple impacts and large number of stakeholders that combine to make the situations more difficult to understand and assess. Addressing sustainability issues adds to the complexity of transport planning situations. So, to deal with this complexity, we believe that multi criteria decision making approaches are needed. The main scope of the proposed multi criteria decision support framework is to undertake a comprehensive sustainability assessment of a large transport infrastructure project, in which a variety of criteria, and stakeholders' views of their importance, must be taken into account. The sustainability aspects are addressed based on the information about identified and relevant criteria and the associated stakeholders' common vision of an explicit sustainability strategy. The analytic hierarchy process (AHP) is a powerful and flexible decision making process to helps people to set priorities and make the best decision when both qualitative and quantitative aspects of a decision are needed to be considered. In AHP decision making is done by reducing complex decisions to a series of one-on-one comparisons, then synthesis the results. The analytic hierarchy process (AHP) is a structured technique for helping people to deal with complex decisions. Rather than prescribing a "correct" decision, the AHP helps people to determine one, based on mathematics and human psychology. In AHP, the general complex problem is decomposed into a multi-level hierarchical structure of objectives, criteria, Sub-criteria and alternatives. AHP can be used in making decisions that are complex, unstructured, and contain multiple attributes.

The decisions that are described by these criteria do not fit in a linear framework; they contain both physical and psychological elements. AHP provides a method to connect, that can quantify the subjective judgment of the decision maker in a way that can be measured. In applying AHP to benchmarking, the process is described in three broad steps: the description of a complex decision problem as a hierarchy, the prioritization procedure, and the calculation of results. AHP is a method of breaking down a complex, unstructured situation into its component parts, arranging these parts or judgments on the relative importance of each variable, and synthesizing the judgments to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation (Saaty, 1990). A problem is put into a hierarchical structure with level-I, reflecting the overall goal or focus of the decision. Level-II contains factors or criteria for the decision, level-III contains sub-factors, and level-IV contains the decision options. The prioritization process is accomplished by assigning a number from a scale to represent the importance of the criteria. A matrix with pair-wise comparisons of these attributes provides the means for calculation. The AHP decision model for the problem is shown in given fig. 1.

III. The Rail Baltica: A Case Study

The case study used to test the proposed decision support framework concerns the Rail Baltica project, which is aims at creating a high-speed, European-gauge railway link from Tallinn in Estonia, through Latvia and Lithuania, to Warsaw in Poland. Trains in the Baltic countries currently run on Russian-gauge tracks, which are not compatible with the European-gauge used in Poland and further west. This creates an obstacle to free and fast movement of goods and citizens between Member States of the European Union. Moreover, the missing links and relatively poor condition of the railway infrastructure in states at the eastern end of the Baltic Sea lead to the stagnation of rail transport, while road transport is rapidly growing and significantly contributing to the negative environmental consequences of transport as a whole. Therefore, the Rail Baltica project aims at providing a fast, safe and sustainable rail transport network that will improve the social, economic and environmental conditions in the region. [20] Investigated the economic potential of three main options for the construction of the Rail Baltica railway line. The alternatives, referred to as investment packages, are illustrated in Fig. given :

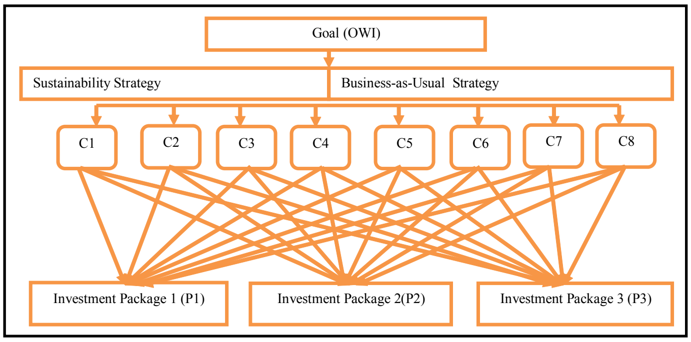

Fig. 1: AHP Decision Framework

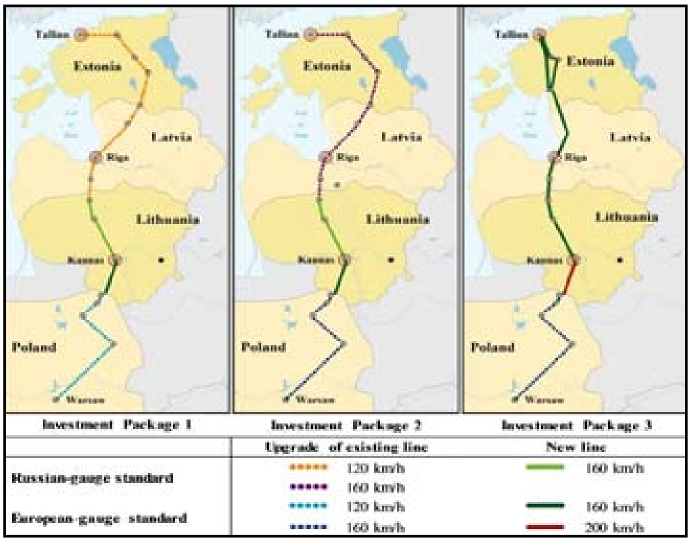

Fig. 2: Investment Packages for Rail Baltica Adapted from [20].

The three investment packages shown in given fig. 2 reflect different levels of improvement in the existing railway network in the Baltic States and Poland. Each package has a different combination of the new alignments, additional track, and upgrades of the old track in the existing alignments, to secure a defined design speed. Investment Package 1 with a construction cost of EUR 9791 million represents the minimal upgrade of the railway network to enable a minimum design speed of 120 km/h from Tallinn to Warsaw. Investment Package 2 with construction cost of EUR 1, 5461 million represents a fairly ambitious plan for the upgrade of the railway network to enable a minimum design speed of 160 km/h. Finally, Investment Package 3 with the budget of EUR 2, 3691 million reflects the most ambitious plan for the railway connection in which an electrified European-gauge railway line would be built along the entire corridor from Tallinn to Warsaw. Table 1 describes each package's specification in detail.

The assessment of the alternatives in the preliminary study by [20] was based solely on monetary impacts because, at that time, the decisive question was, whether the investment packages were economically feasible or not for the further examination and analysis. However, besides the monetary impacts, the new infrastructure will have other impacts, which are obviously left out in a purely economic assessment. So, for managing sustainable transport development a more comprehensive assessment is needed, in which all the relevant impacts can be taken into account in a balanced way.

The two strategies are identified for the system namely Sustainability Strategy & Business-as-Usual Strategy. The eight sets of decision criteria are presented as input for the AHP framework after a discussion, approved by the participants as

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criteria for a comprehensive assessment of the three investment packages:

1. Accessibility and effect on the transport network (C1). This criterion emphasizes the impact of the alternatives on accessibility for both the passengers and freight transport.
2. Contribution to the EU green corridors (C2). This criterion emphasizes the potential of the alternatives in promoting green corridors. The European concept of "Green Corridors" denotes long-distance freight transport corridors relying on co-modality and advanced technology to accommodate rising traffic volumes while at the same time encouraging environmental sustainability and energy efficiency.
3. Effect on tourism (C3). This criterion emphasizes the potential of the alternatives in promoting tourism and attracting tourists to the region.
4. Environmental and ecological effect (C4). This criterion covers the impact of the alternatives on the environment in the region, including issues related to land-use, effects on animals in the region and their habitats, and disturbance to the surrounding area.
5. Health (C5). This criterion considers the impact of the alternatives on the community's health with regard to the emission of noise and air pollutants.
6. Location of companies and logistics centers (C6). This criterion covers the impact of the alternatives on the current location of companies and logistics centers as well as their potential to attract new ones.
7. Regional development (C7). This criterion considers the potential of the alternatives in contributing to the overall development of the region, i.e. the elements that make up society's performance and well-being.
8. Robustness of feasibility (C8). This criterion embraces the overall economic performance of the alternatives by considering the certainty graphs stemming from risk analysis.

IV. Steps of AHP

Saaty [21] developed the following steps for applying the AHP:

1. Define the problem and determine its goal.
2. Structure the hierarchy from the top (the objectives from a decision maker's viewpoint) through the intermediate levels (criteria on which sub sequent levels depend) to the lowest level which usually contains the list of alternatives.
3. Construct a set of pair-wise comparison matrices (size n x n) for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale measurement shown in Table 1. The pair-wise comparisons are done in terms of which element dominates the other.
4. There are n (n-1) judgments required to develop the set of matrices in step 3. Reciprocals are automatically assigned in each pair-wise comparison.
5. Hierarchical synthesis is now used to weight the eigen vectors by the weights of the criteria and the sum is taken over all weighted eigen vector entries corresponding to those in the next lower level of the hierarchy.
6. Having made all the pair-wise comparisons, the consistency is determined by using the eigen value λmax, to calculate the consistency index using the following formulae.

$$CI = (\lambda max - n)/(n-1)$$

the consistency ratio is then calculated using the formulae

$$CR = CI/RCI$$

Where CI = Consistency index, CR = Consistency ratio, RCI = Random consistency index, n = Number of elements

Judgment consistency can be checked by taking the consistency ratio (CR) of RCI with the appropriate value. The CR is acceptable, if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent.

Table 1: The Three Investment Packages for the Rail Baltica Railway Corridor and Their Specifications

Connection	Section	Description		
		P1	P2	P3
Tallinn-Riga	Tallinn-EE/LV Border	No upgrade of the existing line.	Upgrade of the existing line via Tartu to 160 km/h.	Construction of a new line based on European standard gauge via Parnu. Design speed of 160 km/h. Not electrified.
	EE/LV border-Riga	Upgrade of the existing line via Valmiera to 120 km/h.	Upgrade of the existing line via Valmiera to 160 km/h	Construction of a new line based on European standard gauge from Parnu to Riga. Design speed of 160 Km/h. Not electrified.
Riga-Kaunas	Riga-LV/LT Border	Upgrade of the existing line via Jelgava to 120 km/h.	Upgrade of the existing line via Jelgava to 160 km/h.	Construction of a new line based on European standard gauge via Jelgava. Design speed of 160 km/h. Electrified.
	LV/LT border-Kaunas	Construction of a new line from Joniskis to Kaunas via Radviliskis. Design speed of 160 km/h.		Construction of a new line based on European standard gauge via Joniskis and Radviliskis. Design speed of 160 km/h. Electrified.
Kaunas-Warsaw	Kaunas-LT/PL Border	Construction of a new line based on European standard gauge. Design speed of 160 km/h. Not electrified.		Construction of a new line based on European standard gauge. Design speed of 200 km/h. Electrified.
	LT/PL border-Warsaw	Upgrade of the existing line via Elk to 120 km/h.	Upgrade of the existing line via Elk to 160 km/h.	Upgrade of the existing line via Elk to 160 km/h. Electrified.

Table 1: Pair Wise Comparison Between Criteria's

Criteria	Sustainability Strategy	Business Strategy
Sustainability Strategy	1	5
Business Strategy	1/5	1

Table 2: Pair wise Comparison between criteria's normalized value

Criteria	Sustainability Strategy	Business Strategy	E-Vector
Sustainability Strategy	1	5	0.8333
Business Strategy	1/5	1	0.1667

Table 3. Pair wise comp. C1 and alternatives

C1	P1	P2	P3	E-vector
P1	1	7	9	0.79276
P2	1/7	1	2	0.13122
P3	1/9	½	1	0.07602

7. Steps 3-6 are performed for all levels in the hierarchy.

V. Application of the AHP to the Rail

A. Baltica Case

Table 4: Sub-criteria Pair wise Comparison Business Strategy

Sub-criteria	C1	C2	C3	C4	C5	C6	C7	C8	e-vector
C1	1	2	5	3	1/3	½	1/2	1/3	0.11071
C2	½	1	½	3	2	1/3	½	1/3	0.07231
C3	1	2	1	4	2	½	½	½	0.10748
C4	1/5	1/3	¼	1	½	1/7	1/6	1/8	0.02599
C5	1/3	½	½	2	1	¼	¼	1/5	0.04539
C6	2	3	2	7	4	1	2	½	0.20615
C7	2	2	2	6	4	½	1	½	0.16164
C8	3	3	2	8	5	2	2	1	0.27033

The top-level criteria in this model are Sustainability Strategy & Business-as-Usual Strategy. In the second level of hierarchy, eight sub-criteria termed as dimensions of the model is placed which supports the two determinants at the top level of hierarchy. The alternatives are presented at last level of hierarchy. After obtaining the pair-wise judgments as in Table 1, the next step is the computation of a vector of priorities or weighting of elements in the matrix. In terms of matrix algebra, this consists of calculating the "principal vector" (eigenvector) of the matrix by adding the members of each column to find the total. In the next step, in order to normalize each column to sum to 1.0 or 100%, divide the elements of that column by the total of the column and sum them up. Finally, add the elements in each resulting row and divide this sum by the number of elements in the row to get the average. The example of such matrix is shown in Table 2.

For example, the value 0.8333 in Table 2 is obtained by dividing 1 (from Table 2) by the sum of the column items in Table 2. The priority vector in Table 2 can be obtained by finding the row averages. For example, the priority of strategy with respect to the criterion `experience' in Table 2 is calculated by dividing the sum of the rows by the number of contractors (columns), i.e., 5, in order to obtain the value 0.8333. The priority vector for experience, indicated in Table 2, is given below.

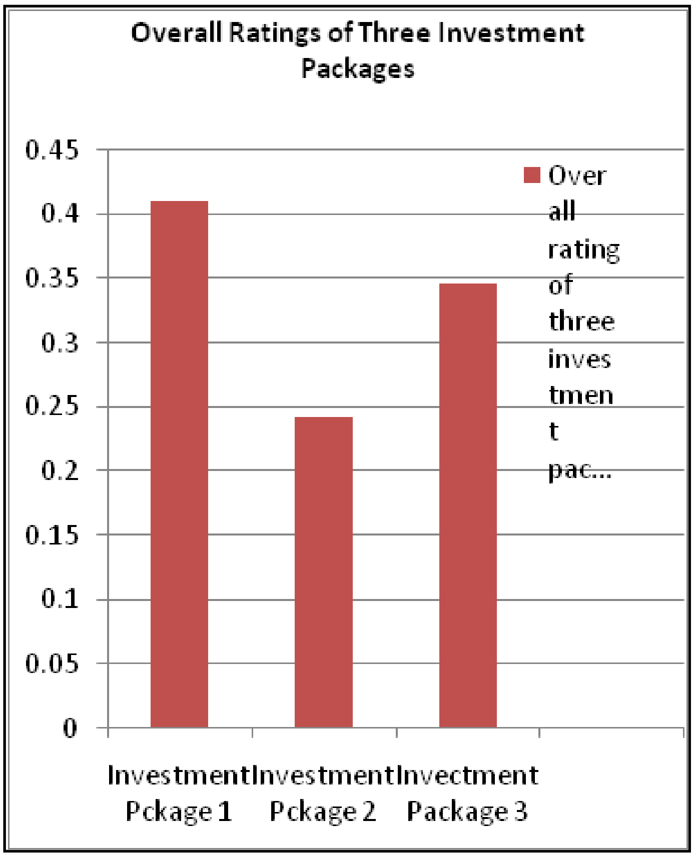

Fig. 3: Rail Transport Investment Package Rating

Table 6. Composite relative weight

Issues	Relative Weight Using AHP	Factor	Relative Weight Using AHP	Global Weight
Sustainability Strategy	0.8333	C1	0.20705	0.172535
		C2	0.07407	0.061723
		C3	0.04639	0.038657
		C4	0.23832	0.198592
		C5	0.11881	0.099004
		C6	0.17986	0.149877
		C7	0.10865	0.090538
		C8	0.02687	0.022391
Business Strategy	0.1667	C1	0.11071	0.018455
		C2	0.07231	0.012054
		C3	0.10748	0.017917
		C4	0.02599	0.004333
		C5	0.04539	0.007567
		C6	0.20615	0.034365
		C7	0.16164	0.026945
		C8	0.27033	0.045064

Table 7. Overall Rating of Three Investment Packages Using AHP

Issues	Factor	Relative Weight Using AHP						
			P1	P2	P3	P1	P2	P3
Sustainability Strategy	C1	0.172535	0.79276	0.13122	0.07602	0.136778847	0.022640043	0.013116111
	C2	0.061723	0.07072	0.17818	0.75140	0.004365051	0.010997804	0.046378662
	C3	0.038657	0.06789	0.16176	0.77031	0.002624424	0.006253156	0.029777874
	C4	0.198592	0.71707	0.21717	0.06577	0.142404365	0.043128225	0.013061396
	C5	0.099004	0.06033	0.23115	0.70852	0.005972911	0.022884775	0.070146314
	C6	0.149877	0.47059	0.47059	0.05882	0.070530617	0.070530617	0.008815765
	C7	0.090538	0.06577	0.21717	0.71707	0.005954684	0.019662137	0.064922084
	C8	0.022391	0.06577	0.21717	0.71707	0.001472656	0.004862653	0.016055914
Business Strategy	C1	0.018455	0.79276	0.13122	0.07602	0.014630386	0.002421665	0.001402949
	C2	0.012054	0.07072	0.17818	0.75140	0.000852459	0.002147782	0.009057376
	C3	0.017917	0.06789	0.16176	0.77031	0.001216385	0.002898254	0.013801644
	C4	0.004333	0.71707	0.21717	0.06577	0.003107064	0.000940998	0.000284981
	C5	0.007567	0.06033	0.23115	0.70852	0.000456517	0.001749112	0.005361371
	C6	0.034365	0.47059	0.47059	0.05882	0.016171825	0.016171825	0.002021349
	C7	0.026945	0.06577	0.21717	0.71707	0.001772173	0.005851646	0.019321451
	C8	0.045064	0.06577	0.21717	0.71707	0.002963859	0.009786549	0.032314042
Overall						0.411274224	0.242927241	0.345839284

VI. Results and Discussions

AHP approach applying in multi-criteria decision analysis can be seen as potentially useful by including all the impacts relevant to the decision problem in hand, in a comprehensive assessment. In this way, not only economic, but also other impacts including sustainability issues are incorporated in the evaluation framework. However, then the problem is not so much a matter of including non-economic impacts, but of defining their importance relative to economic impacts. For this, what needed is the involvement of the various stakeholders and participants in the decision-making process.

This also relates to another difficult issue – the communication deficit between planers ("visionaries") and economists ("calculators") in the appraisal process. In the light of this contemporary assessment methodology discussion, the proposed AHP approach using different strategies based on the ranking of criteria by order of importance makes it possible to incorporate all the various viewpoints of the stakeholders present at the decision-making process. As [9, 28-29] have stressed, addressing sustainability or other important aspects must be done through a planning process which effectively engages all the different stakeholders in creating their vision in relation to the decision problem in hand. So, the assessment must be supported by a process of interaction between the various stakeholders at a decision conference. In this way, the comprehensive assessment will be affected by both the process and the assessment modeling, making it possible to see the outcome as a common, vision-based decision [30]. The results of comprehensive assessment achieved by AHP can be seen as desirable because it is more likely that they take account of all the various stakeholders' views. With regard to the identification of the criteria relevant for the explicit sustainability strategy, this necessitates the participation of stakeholders fully capable of identifying the relevant measures for sustainability. This will lead to make use of indicators that are suitable for the actual decision problem. So, the listing and ranking of criteria that measure the strength of the three investment packages in fulfilling the sustainability objectives could be improved with the help of real stakeholders.

V. Conclusion

Transport decision-making often relies on impacts that are not easy to measure in monetary terms. So, it has become important to explore project alternatives in a wider context, in which relevant strategic, long-term issues are taken into account in this AHP Model non-monetary issues are introduced together with the criterion of robustness of feasibility based on the feasibility risk assessment. The latter is intended to cover the overall economic impact of each alternative considered, allowing for the appropriate inclusion of strategic criteria of importance for the comprehensive assessment. With growing attention to sustainability issues in transport planning, we have aimed in this paper at focusing on the various long-term, strategic criteria, to make it possible to give high priority to the sustainability point of view. The proposed decision support framework, using the AHP, methodology in a planning process that includes a decision conference, provides the means to assess a decision problem in a comprehensive way with a priority focus on sustainability. Exploring the sustainability strategy can help find the best sustainable alternative given that the criteria used are found relevant to express the issues relating to sustainability. Therefore we see the proposed AHP approach as of interest for managing sustainable transport development. One major concern in this respect is whether the stakeholders feel assisted and confident about the way the vision-based decisions about sustainable transport development are achieved through the model and process-based approach described.

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Appendix

Pair wise comparison between Alternatives

Table 9. Pair wise comparison between C1 and alternatives

C1	P1	P2	P3	E-vector
P1	1	7	9	0.79276
P2	1/7	1	2	0.13122
P3	1/9	½	1	0.07602

Table 10. Pair wise comparison between C2 and alternatives

C2	P1	P2	P3	E-vector
P1	1	1/3	1/9	0.07072
P2	3	1	1/5	0.17818
P3	9	5	1	0.75140

Table 11: Pair Wise Comparison Between C3 and Alternatives

C3	P1	P2	P3	E-vector
P1	1	1/3	1/9	0.06789
P2	3	1	1/6	0.16176
P3	9	6	1	0.77031

Table 12. Pair wise comparison between C4 and alternatives

C4	P1	P2	P3	E-vector
P1	1	4	9	0.71707
P2	¼	1	4	0.21717
P3	1/9	¼	1	0.06577

Table 13: Pair wise comparison between C5 and alternatives

C5	P1	P2	P3	E-vector
P1	1	1/5	1/9	0.06033
P2	5	1	¼	0.23115
P3	9	4	1	0.70852

Table 14: Pair wise comparison between C6 and alternatives

C6	P1	P2	P3	E-vector
P1	1	1	8	0.47059
P2	1	1	8	0.47059
P3	1/8	1/8	1	0.05882

Table 15: Pair wise comparison between C7 and alternatives

C7	P1	P2	P3	E-vector
P1	1	¼	1/9	0.06577
P2	4	1	¼	0.21717
P3	9	4	1	0.71707

Table 16: Pair wise comparison between C8 and alternatives

C8	P1	P2	P3	E-vector
P1	1	¼	1/9	0.06577
P2	4	1	¼	0.21717
P3	9	4	1	0.71707

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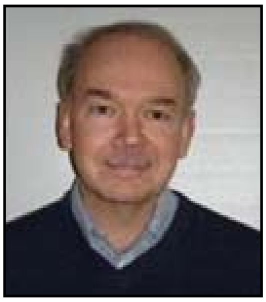

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