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## SELECTION OF OPTIMUM FUEL BLEND IN AN IC ENGINE USING FAHP-PROMETHEE

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### Abstract:

Energy is important criteria in determining the world's economy. The increasing demand on energy due to industrialisation, population growth and rise of living standards have led to considerable use of fossil fuels. Biodiesel proves to be a good alternative for fossil fuels. But the feasibility of biodiesel is the major factor for determining it as an alternate fuel for CI engines. The selection of suitable biodiesel with the appropriate blend for the IC engine plays a vital role in the energy sector. The objective of this study to identify the apt fuel blend using FAHP-PROMETHHE. FAHP method is applied to find the relative weights of the criteria, while PROMETHEE has been used to identify the best alternatives. NO<sub>x</sub>, Smoke, HC, CO, CO<sub>2</sub>, BTE, EGT, ID, CD and MRPR were considered as the assessment criteria. From the results, it is observed that B20 is the best blend.

Keywords: Energy, Fish oil, Diesel, Engine, Emission, MCDM, FAHP

### 1. Introduction

With the rapid development of the global economy, energy requirements have increased remarkably. Energy is central to achieve the inter related goals of modern societies to meet human needs. The realization that fossil fuel resources required for the generation of energy are becoming scarce. The average global energy consumption grows at the rate of 1.6 % p.a. This indiscriminate consumption of fossil fuels will lead to depletion of petroleum reserves between 2050 and 2075 [1]. It is mandatory to shift the energy supply system from the fossil fuel to the renewable alternative fuel. Biofuels are the convincing alternative for the fossil fuels since they are less pollutant, ecological and 100% natural fuel with the similar properties to diesel which enhances the energy security. A few researches are going around the world in search of alternative renewable fuels for diesel engines. The important advantage in using biodiesel as an alternate fuel is that it can be used in diesel engine without any modification.

Biodiesel can be produced from renewable resources by combining vegetable oils and animal fats with an alcohol to form alkyl esters which enhances the energy security and economy independence [2]. The cultivation of crops for biodiesel production poses a threat to food security and also contributes to drop in soil richness [3]. In the meantime, the animal fat present in the waste parts of fish attends to be a best alternative for biodiesel. It is assessed that, consistently, a surplus quantity of fish parts is disposed by different fish products manufacturers at every year. More than one lakh tonnes of shrimp were produced as industrial fish waste as stated by Central Institute of Fisheries Technology (CIFT). The global fish oil production was 1.01 million tonnes as stated by International Fishmeal and Fish Oil Organization (IFFO) and it will be increased tenfold by next 5 years [4]. Hence, fish oil has increasing attention to be a good source of biodiesel for diesel fuel subsequently reducing the ecological pollutants and energy crisis. Jayasinghe and Hawboldt analysed the fish oil properties and identified the possibility of using fish oil as a biodiesel [5]. Considerable researchers examined the engine performance characteristics operated with fish oil as a biodiesel [6-17]. The test results showed that the engines operated normally with reduction in emissions and increase in efficiency with no apparent adverse operational or maintenance impacts. Hence an effort has been made to analyse the engine performance characteristics using ethyl ester of fish oil as a biodiesel. The performance, emission and combustion parameters of the engine are considered at different load conditions for choosing the optimum blend which is a difficult task [18-21]. To overwhelm the shortcomings of the existing research, all the performance, emission and combustion characteristics are considered in this research.

MCDM provides sophisticated methodological tools that are oriented towards the support of the decision makers in facing complex real-world decisions. The use of MCDM in the automotive has been



progressively increasing in the past couple of decades. Poh and Ang (1999) applied an AHP technique to identify and evaluate the best alternative fuel for land transportation in Singapore [22]. Goumas and Lygerou (2000) ranked the alternative energy projects using PROMETHEE method in fuzzy environment [23]. Yedla et al (2003) have developed a multi-criteria decision making model for the selection of alternative options for environmentally sustainable transport system in Delhi [24]. Tsita and Pilavachi (2012) performed the evaluation of alternative fuels for the transport sector using FAHP [25]. Etghani et al. (2013) investigated the performance of a diesel engine by considering environmental criteria [26]. Sakthivel et al. (2013) applied PROMETHEE for evaluation of an automobile purchase model [27]. Chand (2017) proposed PROMETHEE to identify a sedan car by considering various criteria [28].

The aforementioned literature sections confirmed the significance of MCDM methods in the blend selection. It has also identified that there is no trace of research that deals with MCDM technique PROMETHEE with FAHP for the selection of suitable fuel blend based on the performance, combustion and emission characteristics. Hence this paper proposed a novel hybrid MCDM technique for evaluating optimum blend to achieve maximum engine performance and minimising environmental pollution.

## 2. Experimental Procedure

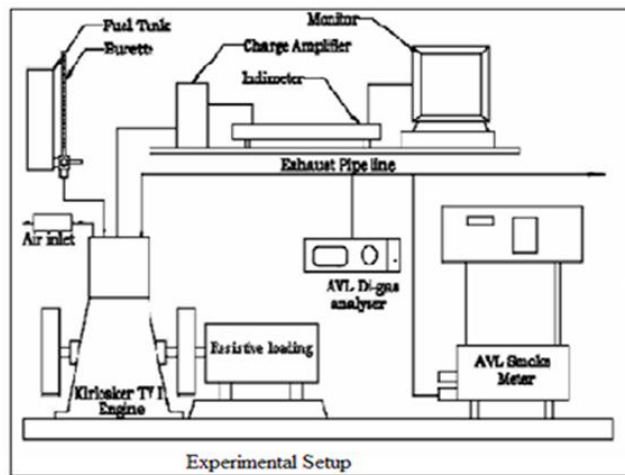


Figure 1. Schematic diagram of the engine setup

A four stroke single cylinder, direct injection, air cooled, constant speed, compression ignition engine was used in the test. The schematic diagram of the engine setup is shown in Figure 1. The engine was coupled to an electrical dynamometer with a control system to provide the brake load. The fuel consumption was measured by a burette and a stop watch. A provision was made to mount a piezoelectric pressure transducer on the cylinder head surface in order to measure the in-cylinder pressure. The pressure transducer was connected to a charge amplifier to condition the signals. A series of tests were carried out at a constant speed by varying the concentrations of the blends such as diesel and biodiesel with 20% interval. Each test was repeated three times to ensure the reproducibility of data and shown in Table 5. The AVL 437 smoke meter was used to measure the intensity of smoke and AVL 444 di gas analyser to measure the levels of carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), oxides of nitrogen (NO<sub>x</sub>) and hydrocarbon (HC) emissions. Technical specifications of the test engine are given in the Table 1. From the measured values, the performance parameters brake power, specific fuel consumption and brake thermal efficiency were calculated.

## 3. Literature Review

### 3.1 FAHP method

AHP method is proposed by Saaty (1980) [29]. In AHP, the decision problem is structured hierarchically at different levels with each level consisting of a finite number of elements (Khajeeh, 2010) [30]. A fuzzy set is characterized by a membership function which assigns a grade of membership ranging between zero and one to each object of the class (Zadeh, 1965) [31]. Fuzzy logic is integrated with AHP and proposed

as FAHP [32]. The shape of the membership functions can be either trapezoidal or triangular according to the situation. However, the triangular fuzzification method was most often used as it is the simplest and widely used method [33-34]. The reason for using a triangular fuzzy number is that it is instinctively easy for the decision-makers to use. Modelling using triangular fuzzy approach enables the experts to deal better with the vague decision problems [35]. According to the nature of TFN, it can be defined as triple points (p,q,r). Here P and R represent the fuzzy probability between the lesser and higher boundaries of evaluation. The triangular fuzzy number is shown in Figure 2. From the literature, it is observed that FAHP has been extensively applied in many complex decision making problems. Sakthivel et al. (2016) incorporate this technique to identify the criteria weights of the engine performance parameters [36]. Shen et al. (2010) incorporate this technique for exploiting renewable energy sources [37]. Afsordegan et al (2016) applied this technique for assessing the weights to criteria to find the best energy alternative [38]. Sivaraajet al. (2017) used this technique for assessed renewable energy development in the engines [39]. The procedural steps of FAHP are shown below:

Step 1. The hierarchy is structured with respect to the criteria for a complex decision making problem. It has three levels in which objective of the study is at top, multi criteria attributes defines in the middle section and the alternatives at the bottom [56]. The objective of hierarchy is ultimately to find out the alternatives.

Step 2. The crisp pair wise comparison matrix is fuzzified using TFN  $M = (p, q, r)$  where p and r are indicates higher and lower range respectively that may exist in the preference criteria of decision maker's criteria.  $M_1, M_2, M_3, M_4, M_5, M_6, M_7, M_8, M_9$  are the membership function to indicate the assessment. The membership function of triangular fuzzy number for FAHP are expressed on five scales and also listed in Table 2.

Let  $Q = \{Q_j, j = 1, 2, \dots, z\}$  be a set of criteria. The result of the pair-wise comparison on 'z' criteria can be summarized in an  $(z \times z)$  evaluation matrix T in which every element  $t_{ij}$  ( $i, j = 1, 2, \dots, z$ ) is the quotient of weights of the criteria, as shown:

$$T = \begin{bmatrix} t_{11} & t_{12} & \dots & \dots & t_{1z} \\ t_{21} & t_{22} & \dots & \dots & t_{2z} \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ t_{z1} & t_{z2} & \dots & \dots & t_{zm} \end{bmatrix} \quad t_{ii} = 1, t_{ji} = \frac{1}{t_{ij}}, t_{ij} \neq 0. \quad (1)$$

Step 3. The mathematical process is normalized to identify the relative weights of decision criteria which is in each matrix. The relative weights are given by using right Eigen vector (Z) which relates to the maximum (largest) Eigen value  $\lambda_{\max}$  as

$$T_z = \lambda_{\max} z \quad (2)$$

The consistency of the pair-wise comparison matrix is defined by the relation between entries of T ;  $t_{ij} \times t_{jk} = t_{ik}$ .

And hence the consistency index is

$$CI = \frac{\lambda_{\max} - z}{z - 1}. \quad (3)$$

Step 4. The pair wise matrix is normalized and the weights are prioritized. The values in this priority are summing equal to 1. The consistency ratio (CR) is the ratio of consistency index (CI) with random consistency index (RCI) using pair wise comparison matrix and it is indicated below

$$CR = \frac{CI}{RCI}. \quad (4)$$

Table 3 lists the value of the RCI for matrices of order 1 to 10 obtained by approximating random indices using a sample size of 500.

The acceptable CR range varies as per the matrix size and for 3 x 3 matrix is 0.05, for 4 x 4 matrix is 0.08 and for all greater matrices is 0.1. The value of CR is equal to, or less than the range shows that the evaluation matrix is acceptable which implies the consistency level is good. If it is more than the value, there is an inconsistency and therefore evaluations have to be reconsidered or reviewed until it improves.

### 3.2 PROMETHEE method

PROMETHEE is MCDM method for ranking a solution of any alternatives with respect to its related criteria which developed by Brans et al. [41]. Since it follows transparent computations and easily

understandable it is best known method for outranking. PROMETHEE introduces preference functions to describe the decision maker's preferences along each criterion which is characterized by ease of use and decreased complexity. It also identifies the difference level between alternatives while calculating the ranking priority. Mladineo et al. (1987) proposed the technique for alternative location ranking [42]. Tzeng and Shiau (1987) applied PROMETHEE to analyse the strategies of energy conservation strategies in urban transportation [43]. Turcksin et al. (2011) identified a multi-instrumentality policy to reduce environmental externalities by selecting the most appropriate energy policy scenario using this technique [44]. Alsayed et al. (2014) used this technique for design of hybrid power generation systems [45]. Wei et al. (2016) proposed this technique for study of grid energy storage systems [46]. The procedure for PROMETHEE is explained below.

Step 1 Normalization of the decision matrix

$$Y = \frac{z_{ij}}{\sqrt{\sum z_{ij}^2}} \quad (5)$$

Step 2 Computation of the evaluative difference of  $k^{th}$  alternative with other alternatives

The differences in each criteria value is calculated for different alternatives in a pair wise manner.

Step 3 Compute the preference function

The preference function requires the definition of some preferred parameters such as the parameter which is to be preferred or indifference. But in real world application it is difficult to find such parameter for decision makers. Hence the following simple preference function is employed.

$$P_l(k, k') = 0 \text{ if } Y_{kl} < Y_{k'l} \quad (6)$$

$$P_l(k, k') = (Y_{kl} - Y_{k'l}) \text{ if } Y_{kl} > Y_{k'l} \quad (7)$$

Step 4 Calculate the aggregated preference function

The aggregated preference function is calculated by considering the weights for each criterion using the below equation

$$S(k, k') = \frac{\sum_{l=1}^m v_l \times P_l(k, k')}{\sum_{l=1}^m v_l} \quad (8)$$

Where  $v_l$  is the relative importance or weight for the  $l^{th}$  criterion.

Step 5 Determination of leaving flow and entering flow

The leaving flow or positive flow of  $k^{th}$  alternative is calculated as,

$$\varphi^+(k) = \frac{1}{n-1} \sum_{k'=1}^n S(k, k') \quad (k \neq k') \quad (9)$$

The entering or negative flow for  $k^{th}$  alternative is calculated as,

$$\varphi^-(k) = \frac{1}{n-1} \sum_{k'=1}^n S(k', k) \quad (k \neq k') \quad (10)$$

Where  $n$  is the number of alternatives.

In this application for each alternative there are  $(n-1)$  other alternatives.

The entering flow determines how much a one alternative is conquered by other alternative and the leaving flow identifies how much one particular alternative governs the other alternatives. PROMETHEE I provide partial outranking for the alternatives based on the leaving and entering flows.

Step 6 Calculating net outranking flow

$$\varphi(k) = \varphi^+(k) - \varphi^-(k) \quad (11)$$

Step 7 Determination of the outranking values

The ranking of the alternatives can be determined based on the net outranking flow. Higher the value of net outranking flow is the better alternative.

#### 4. THE PROPOSED MODEL

The proposed model contains of three basic phases to evaluate the best blend namely, exploratory observations, criteria weights computations, applying PROMETHEE to identify the suitable blend. Exploratory analysis was carried out in a four stroke single cylinder, direct injection, air cooled, constant speed and variable load, compression ignition engine to observe the performance and emission characteristics. In the second stage, the decision hierarchy is structured using the assessed criteria and the alternative blends. Third, the relative weights of the identified criteria are calculated using FAHP. Based on the percentage of relative weights of each criterion, the impact on the ranking may be changed. The calculated weights are given as the input for PROMETHEE method to evaluate the best alternative.

## 5. COMPUTATIONS

In this investigation, the authors have identified the evaluation criteria from the literature to select the best blend. The criteria are prioritized in the decision making process as per the collective feedback from the experts. Oxides of Nitrogen, Smoke, Brake thermal efficiency, Carbon dioxide, Carbon monoxide, Hydrocarbon, Exhaust gas temperature, Ignition delay, Combustion duration, Maximum rate of pressure rise are the criteria considered.

### 5.1. FAHP-PROMETHEE

#### 5.1.1. Identification of weights using FAHP

The decision hierarchy is framed with the use of identified criteria and the alternatives. Here, a feedback is collected from the engine experts and the manufactures to identify the relative importance of the criteria by comparing one with other using questionnaire design. Experts ranked the criteria to meet the better efficiency and minimum emissions. The relative weights are calculated using pair wise comparison matrix with satty's scale. The pair wise decision matrix with respect to the ten criteria is framed using equation 1. The relative weights and consistency ratio of the criteria are also computed from the pair wise comparison analysis using equations 2-4. From the relative analysis, it is identified that Oxides of Nitrogen and smoke is the significant emission factor by stands first and second with the relative weight. The identified criteria with the relative weights using pair wise comparison process are detailed in Table 4.

#### 5.1.2 Determination of best alternative using PROMETHEE

The computational steps of the PROMETHEE are demonstrated below for 50% load to identify the suitable blend with the observed engine performance parameters.

Step 1: Normalize the experimental performance and emission parameters of engine by equation 5

Step 2: The preference (P) functions are calculated using equations 6 and 7 is given below. for each criterion at various loads and shown in Table 6.

Step 3: The weighted preference function is calculated using FAHP weights for each criteria and also shown in Table 7.

Step 4: The resulting aggregated (S) preference function is calculated using equation 8 for all the blends with different loads and detailed in Table 8.

Step 5: The leaving and negative flow is then computed using equations 9 and 10 and shown in Table 9.

Step 6: The net outranking flow values is computed using equation 11 and tabulated in Table 10. Based on the net outranking values, rank for each alternative were obtained.

A similar computation is carried out for no load, 25%, 75% and 100% load to identify the best blend.

## 6. RESULTS AND DISCUSSION

The results of the proposed method FAHP and PROMETHEE is detailed in Table 10. From the observed outranking values, it is identified that B20 blend stands first at 50%, 75% and 100% load and second at no load and 25% load. It is observed that B20 is the suitable blend among the all alternatives to minimise the emissions by improving the engine efficiency. Generally, the influence of performance, emission and combustion characteristics of the engine with respect to the load and blend differs and it is challenging for the researchers to identify the suitable alternative among the different alternatives. The fuel characteristics are also closer which creates inconsistency to satisfy the emission norms and meet the fuel economy. To overwhelm the above problem, the computational model of FAHP with PROMETHEE was proposed to identify the suitable fuel blend.

## CONCLUSION

The selection of optimum blend will provide a vehement support to enhance the biodiesel usage in IC engines. The suggested hybrid decision method will assist the engine experts and researchers to identify the suitable blend to improve the energy competence in the engines. In multi criteria group decision making process, the decision makers may not express their opinions exactly in the numerical values. So, fuzzy sets are implemented to eliminate the uncertainties arising with the decision maker's opinions. The proposed hybrid MCDM method is perfect and effective tool for the experts to determine the apt blend between different alternatives.

Table 1 Engine specifications

Items	Specification
Make	Kirloskar
Cylinder number	1
Type	Four-stroke, stationary, constant speed, direct injection, air cooled, diesel engine
Bore x stroke	80mm x 110mm
Displacement	661cc
Compression ratio	17.5 : 1
Max. power/speed	4.4 kW/ 1500rpm
Injection timing	24° bTDC
Injection pressure	210bar

Table 2 Pair wise relative importance

Degree of Preference	Definition	Explanation
(1 1 1)	Equally Preferred ( $M_1$ )	Two activities contribute equally to the objective
(2 3 4)	Moderately Preferred ( $M_3$ )	Experience & judgment slightly favor one activity over another
(4 5 6)	Strongly Preferred ( $M_5$ )	Experience & judgment strongly or essentially favor one activity over another
(6 7 8)	Very strongly Preferred ( $M_7$ )	An activity is strongly favored over another and its dominance demonstrated in practice
(8 9 9)	Extremely Preferred ( $M_9$ )	The evidence favoring one activity over another is of the highest possible order of affirmation

Table 3 Random Consistency Index (RCI)

No	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 4 Results obtained with FAHP

Criteria	Weights	$\lambda_{\max}, CI, RCI$	CR
NO <sub>x</sub>	0.2748	$\lambda_{\max} = 11.714$ CI = 0.05 RCI = 1.49	0.034
SMOKE	0.1933		
BTE	0.1698		
CO <sub>2</sub>	0.1132		
CO	0.0851		
HC	0.0558		
EGT	0.0351		
ID	0.0340		
CD	0.0252		
MRPR	0.0137		

Table 5. Experimental performance and emission readings observed from engine for various alternative blends

CRITERIA LOAD	BLENDS	NO <sub>x</sub>	SMOKE	BTE	CO <sub>2</sub>	CO	HC	EGT	ID	CD	MRPR
		(ppm)	(%)	(%)	(%vol)	(%vol)	(ppm)	(°C)	(°CA)	(°CA)	(bar/°CA)
0 %	Diesel	239	5	0	2.2	0.07	29	157	16	46.28	4.55
	B 20	221	10.1	0	2	0.06	27	164	15.9	45.16	4.01
	B 40	219	12.4	0	2	0.06	26	165	15.82	43.08	4.01
	B 60	201	14.2	0	2	0.05	25	168	15.44	44.44	3.48
	B 80	191	11.8	0	2	0.05	24	166	15.42	42.68	3.48
	B 100	178	20.5	0	2	0.04	23	165	15.34	41.135	3.09
25 %	Diesel	519	15.2	17.31	3.2	0.08	35	204	15.16	49.3	5.95
	B 20	522	16	18.03	3.2	0.07	31	205	14.64	47.26	5.61
	B 40	520	16.3	16.32	3.3	0.07	27	211	14.48	44.78	4.81
	B 60	518	19.4	16.3	3.2	0.06	26	212	14.48	45.95	4.08
	B 80	508	20.3	15.69	3.3	0.06	26	204	14.28	44.74	4.01
	B 100	492	25.7	14.54	3.5	0.05	24	215	14.02	41.44	3.38
50 %	Diesel	986	18.5	26.17	4.8	0.09	38	266	14.22	52.14	6.42
	B 20	987	18	27.05	4.5	0.08	34	266	13.64	50.52	5.61
	B 40	964	18.6	24.49	4.5	0.08	29	270	13.52	47.38	4.81
	B 60	944	23.6	23.99	4.7	0.07	31	270	13.42	48.46	4.4
	B 80	935	23.4	21.73	4.7	0.07	29	262	13.24	45.24	4.28
	B 100	904	31.4	22.55	4.9	0.06	28	272	12.84	47.12	3.8
75 %	Diesel	1357	25.8	30.71	6.2	0.09	37	321	13.72	53.28	6.42
	B 20	1358	22.5	30.91	5.8	0.09	35	325	13.52	52.66	5.68
	B 40	1351	23.9	30.41	6	0.08	33	330	13.46	48.28	5.35
	B 60	1346	29.8	27.68	6.2	0.08	31	327	13.42	49.73	5.08
	B 80	1340	28.8	27.16	6.2	0.07	29	332	12.66	51.76	4.55
	B 100	1336	37.4	26.71	6.4	0.07	31	340	11.14	50.34	3.7
100 %	Diesel	1700	32	32.63	8.2	0.11	40	398	13.42	54.81	6.68
	B 20	1689	33.3	34.78	7.4	0.09	37	392	13.38	53.42	6.15
	B 40	1666	36	33.91	7.7	0.09	35	403	13.3	52.22	5.61
	B 60	1642	41.3	31.99	7.7	0.08	32	398	13.04	50.55	5.35
	B 80	1642	41.6	30.17	7.7	0.08	33	397	11.68	49.34	4.55
	B 100	1606	50.9	29.68	8.2	0.07	32	399	10.92	48.94	3.9



Table 6: Preference Function matrix for 50% load

LOAD	BLEND	CRITERA	NO <sub>x</sub>	SMOKE	BTE	CO <sub>2</sub>	CO	HC	EGT	ID	CD	MRPP	
50%	DIESEL	(p1,p2)	0.000	0.009	0.000	0.026	0.054	0.052	0.000	0.018	0.014	0.067	
		(p1,p3)	0.009	0.000	0.030	0.026	0.054	0.116	0.000	0.021	0.040	0.132	
		(p1,p4)	0.018	0.000	0.039	0.009	0.108	0.090	0.000	0.024	0.031	0.166	
		(p1,p5)	0.022	0.000	0.080	0.009	0.108	0.116	0.006	0.030	0.058	0.176	
		(p1,p6)	0.035	0.000	0.065	0.000	0.162	0.129	0.000	0.042	0.042	0.215	
	B20	(p2,p1)	0.000	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(p2,p3)	0.010	0.000	0.046	0.000	0.000	0.064	0.000	0.004	0.026	0.066	
		(p2,p4)	0.018	0.000	0.055	0.000	0.054	0.039	0.000	0.007	0.017	0.099	
		(p2,p5)	0.022	0.000	0.096	0.000	0.054	0.064	0.006	0.012	0.044	0.109	
		(p2,p6)	0.036	0.000	0.081	0.000	0.108	0.077	0.000	0.024	0.029	0.149	
	B40	(p3,p1)	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
		(p3,p2)	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
		(P3,P4)	0.020	0.000	0.030	0.000	0.100	0.000	0.000	0.003	0.000	0.040	
		(P3,P5)	0.012	0.000	0.050	0.000	0.054	0.000	0.012	0.008	0.018	0.044	
		(P3,P6)	0.026	0.000	0.035	0.000	0.108	0.013	0.000	0.021	0.002	0.083	
	B60	(P4,P1)	0.000	0.092	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
		(P4,P2)	0.000	0.101	0.000	0.017	0.000	0.000	0.000	0.006	0.000	0.000	0.000
		(P4,P3)	0.000	0.090	0.000	0.017	0.000	0.026	0.000	0.000	0.009	0.000	
		(P4,P5)	0.004	0.004	0.041	0.000	0.000	0.026	0.012	0.005	0.027	0.010	
		(P4,P6)	0.017	0.000	0.026	0.000	0.054	0.039	0.000	0.018	0.011	0.049	
	B80	(P5,P1)	0.000	0.088	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P5,P2)	0.000	0.097	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P5,P3)	0.000	0.086	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P5,P4)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P5,P6)	0.013	0.000	0.000	0.000	0.054	0.013	0.000	0.012	0.000	0.039	
	B100	(P6,P1)	0.000	0.232	0.000	0.009	0.000	0.000	0.000	0.009	0.000	0.000	0.000
		(P6,P2)	0.000	0.241	0.000	0.035	0.000	0.000	0.000	0.009	0.000	0.000	0.000
		(P6,P3)	0.000	0.230	0.000	0.035	0.000	0.000	0.000	0.003	0.000	0.000	0.000
		(P6,P4)	0.000	0.140	0.000	0.017	0.000	0.000	0.000	0.003	0.000	0.000	0.000
		(P6,P5)	0.000	0.144	0.015	0.017	0.000	0.000	0.015	0.000	0.016	0.000	

Table 7: Weighted Preference function matrix for 50% load

LOAD	BLEND	CRITERA	NO <sub>x</sub>	SMOKE	BTE	CO <sub>2</sub>	CO	HC	EGT	ID	CD	MRPP	
50%	WEIGHTS		0.275	0.193	0.170	0.113	0.085	0.056	0.035	0.034	0.025	0.014	
	Diesel	(p1,p2)	0.000	0.002	0.000	0.003	0.005	0.003	0.000	0.000	0.001	0.000	0.001
		(p1,p3)	0.003	0.000	0.005	0.003	0.005	0.006	0.000	0.000	0.001	0.001	0.002
		(p1,p4)	0.005	0.000	0.007	0.001	0.009	0.005	0.000	0.000	0.001	0.001	0.002
		(p1,p5)	0.006	0.000	0.014	0.001	0.009	0.006	0.000	0.000	0.001	0.001	0.002
		(p1,p6)	0.010	0.000	0.011	0.000	0.014	0.007	0.000	0.000	0.001	0.001	0.003
	B 20	(p2,p1)	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(p2,p3)	0.003	0.000	0.008	0.000	0.000	0.004	0.000	0.000	0.000	0.001	0.001
		(p2,p4)	0.005	0.000	0.009	0.000	0.005	0.002	0.000	0.000	0.000	0.000	0.001
		(p2,p5)	0.006	0.000	0.016	0.000	0.005	0.004	0.000	0.000	0.000	0.001	0.001
		(p2,p6)	0.010	0.000	0.014	0.000	0.009	0.004	0.000	0.000	0.001	0.001	0.002
	B 40	(p3,p1)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(p3,p2)	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P3,P4)	0.005	0.000	0.005	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.001
		(P3,P5)	0.003	0.000	0.008	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.001
		(P3,P6)	0.007	0.000	0.006	0.000	0.009	0.001	0.000	0.000	0.001	0.000	0.001
	B 60	(P4,P1)	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P4,P2)	0.000	0.019	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P4,P3)	0.000	0.017	0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000
		(P4,P5)	0.001	0.001	0.007	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000
		(P4,P6)	0.005	0.000	0.004	0.000	0.005	0.002	0.000	0.000	0.001	0.000	0.001
	B 80	(P5,P1)	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P5,P2)	0.000	0.019	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P5,P3)	0.000	0.017	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P5,P4)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P5,P6)	0.004	0.000	0.000	0.000	0.005	0.001	0.000	0.000	0.000	0.000	0.001
	B 100	(P6,P1)	0.000	0.045	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P6,P2)	0.000	0.046	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P6,P3)	0.000	0.044	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P6,P4)	0.000	0.027	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(P6,P5)	0.000	0.028	0.002	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000

Table 8: Aggregated Preference Function matrix

LOAD	BLEND	Diesel	B 20	B 40	B 60	B 80	B 100
0%	Diesel	-	0.09	0.06	0.05	0.04	0.09
	B 20	0.05	-	0.10	0.05	0.03	0.04
	B 40	0.02	0.03	-	0.05	0.05	0.07
	B 60	0.01	0.02	0.01	-	0.05	0.08
	B 80	0.05	0.05	0.05	0.02	-	0.02
25%	B 100	0.06	0.02	0.01	0.05	0.02	-
	Diesel	-	0.05	0.04	0.04	0.03	0.03
	B 20	0.01	-	0.02	0.03	0.03	0.05
	B 40	0.04	0.01	-	0.01	0.05	0.02
	B 60	0.02	0.01	0.02	-	0.02	0.04
50%	B 80	0.02	0.02	0.02	0.01	-	0.01
	B 100	0.01	0.00	0.01	0.01	0.03	-
	Diesel	-	0.05	0.05	0.05	0.03	0.03
	B 20	0.05	-	0.04	0.06	0.04	0.05
	B 40	0.02	0.02	-	0.02	0.01	0.02
75%	B 60	0.00	0.02	0.02	-	0.03	0.04
	B 80	0.02	0.02	0.02	0.00	-	0.01
	B 100	0.00	0.00	0.01	0.02	0.02	-
	Diesel	-	0.01	0.02	0.02	0.03	0.03
	B 20	0.03	-	0.05	0.04	0.02	0.03
100%	B 40	0.01	0.02	-	0.03	0.03	0.04
	B 60	0.01	0.02	0.02	-	0.00	0.00
	B 80	0.00	0.01	0.02	0.01	-	0.03
	B 100	0.00	0.01	0.01	0.02	0.02	-
	Diesel	-	0.02	0.04	0.03	0.02	0.02
	B 20	0.02	-	0.04	0.04	0.03	0.04
	B 40	0.01	0.01	-	0.01	0.02	0.03
	B 60	0.02	0.02	0.01	-	0.01	0.01
	B 80	0.01	0.01	0.02	0.01	-	0.02
	B 100	0.02	0.02	0.01	0.00	0.01	-

Table 9: Leaving and Entering flow matrix

LOAD \ BLENDS	0%		25%		50%		75%		100%	
	Ψ+	Ψ-	Ψ+	Ψ-	Ψ+	Ψ-	Ψ+	Ψ-	Ψ+	Ψ-
DIESEL	0.07	0.04	0.04	0.02	0.04	0.02	0.02	0.01	0.03	0.01
B 20	0.05	0.04	0.03	0.02	0.05	0.02	0.03	0.01	0.03	0.01
B 40	0.04	0.05	0.03	0.02	0.02	0.03	0.03	0.02	0.01	0.02
B 60	0.03	0.04	0.02	0.02	0.02	0.03	0.01	0.02	0.01	0.02
B 80	0.04	0.04	0.02	0.03	0.01	0.03	0.01	0.02	0.01	0.02
B 100	0.03	0.06	0.01	0.03	0.01	0.03	0.01	0.03	0.01	0.02

Table 10: Net Outranking Flow matrix

LOAD \ BLENDS	0%		25%		50%		75%		100%	
	Ψ	RANK	Ψ	RANK	Ψ	RANK	Ψ	RANK	Ψ	RANK
DIESEL	0.03	1	0.02	1	0.02	2	0.01	2	0.01	2
B 20	0.01	2	0.01	2	0.03	1	0.02	1	0.02	1
B 40	0.00	3	0.00	4	-0.01	4	0.01	3	-0.01	3
B 60	-0.01	5	0.00	3	-0.01	3	-0.01	4	-0.01	4
B 80	0.00	4	-0.02	5	-0.01	5	-0.01	5	-0.01	5
B 100	-0.03	6	-0.02	6	-0.02	6	-0.02	6	-0.01	6

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