Knowledge Based Executive Car Evaluation Using the Evidential Reasoning Approach[1]

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ABSTRACT

This paper presents the application of the Evidential Reasoning (ER) approach to an executive car selection problem. Both quantitative data and qualitative judgements are involved in evaluating each car on individual attributes defining the attractiveness of a car. What would be of interest to both customers and manufacturers is to find a framework in which to combine different types of knowledge for generating an overall picture for each car and furthermore a clear ranking of all cars in question. The ER approach provides a general and flexible framework for such synthesis in a rational way. Details are provided for modelling the car selection problem. Analytic results are generated and discussed using the ER approach.

1. INTRODUCTION

Most real-world decision problems in design of complex engineering products or manufacturing systems involve multiple performance attributes, including both quantitative attributes and qualitative attributes of subjective nature. The evaluation of a design option on a qualitative attribute is inevitably associated with many complex interrelated factors and uncertain subjective judgements. To assess competitive design options, problem often arises as to how numerical numbers and subjective judgements with uncertainty could be used in a consistent and rational way in order to generate a clear ranking order with the decision makers' (designers' or customers') opinions being properly taken into account.

One simple and commonly used way of dealing with the above decision problems is to directly quantify subjective judgements using some numerical scale. Following such quantification, traditional decision making methods like the additive utility function approach

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(1) may be employed to evaluate different design options. However, it is rather difficult to use such a direct quantification method to treat both inaccurate subjective judgements and precise numerical data in a rational and consistent manner. Furthermore, uncertainty and vagueness common in human knowledge cannot be properly catered for in such a method.

In the recent years, an Evidential Reasoning (ER) approach has been developed for dealing with the above complex decision problems in engineering design and in management alike (3), (4). This paper presents the application of the ER approach to the evaluation of several competitive executive cars, including ACURA 3.2TL Premium, BMW 325I, Mercedes Bens C280 and Mazda Mellenia S, to name a few.

The evaluation was conducted by investigating the different achievement levels of each model on many assessment attributes such as *price*, *general dimension*, *performance*, *chassis* and *general finish*. Most of such generic attributes are associated with many other more specific attributes, which are easier to assess directly. For example, *performance* may be assessed through *fuel economy*, *ride quality*, *acceleration*, *braking*, *handling* and so on. Some of these attributes such as *fuel economy* and *acceleration* could be measured by numbers. Others such as *ride quality* and *handling* may be assessed using subjective judgements. The question is then how to combine the mixed numerical and judgmental knowledge to generate an overall ***rational*** evaluation for each model in question.

In this paper, the modelling of the car selection problem is first investigated. The evaluation procedure of the ER approach and the synthesis results for the above executive car selection problem will then be reported in some detail.

2. CAR EVALUATION MODELS

2.1 Performance Criteria

Selecting a car may not be a simple or an easy decision for many people to make. It is equally important for manufacturers to know why customers buy or do not buy their cars. Some people may buy a car simply because they have used the same type of cars for years. Many people, especially first time buyers, however, may choose a car based on the evaluations and comparisons of different types of cars available in the markets.

In evaluation of cars, many factors need to be taken into account apart from *price*, such as *general finish*, *performance*, *chassis* and *general dimension*. These factors are referred to as attributes in this paper. Some attributes such as *price* may be measured directly by numbers. The assessment of some other attributes such as *general finish* may not be so straightforward. They are qualitative in nature and are associated with other factors that are easier to measure. For instance, the evaluation of *general finish* is related to factors like *styling*, *ergonomics*, *noise isolation* and *interior comfort*. In general, a hierarchy of factors can be established for evaluation of qualitative attributes.

Figure 1 shows a typical evaluation hierarchy for car selection. In the hierarchy, factors relevant to car selection are broken down to different levels. At the top level (level 1) is the ranking of cars based on the evaluations of attributes at a level immediately below (level 2). Factors at levels 3 detail relevant attributes at level 2. These factors may be further broken down to lower-level factors if they are still difficult to be measured directly. Factors that are directly measurable are referred to as basic factors in the paper.

In the hierarchy, not all factors at a single level play the same role in the evaluation of a factor associated at a level immediately above. The decision maker may have different views on the importance of factors in evaluation. Among the five attributes at level 2, for example, a customer may consider *performance* as the most important attribute, followed by *price* and *chassis*. *General dimension* and *general finish* may be regarded as relatively less important attributes. This is, however, the customer's individual preference. Another customer may have an entirely different view. Similarly, the relative importance of factors at level 3 associated with the same upper-level attribute also needs to be taken into account.

The relative weight of each attribute is shown by a number in the bracket. For example, the relative weights of *price, general dimension, performance, chassis* and *general finish* are 0.15, 0.1, 0. 5, 0.15 and 0.1 respectively. The relative weights of factors associated with *general dimension* are 0.3 for *cargo capacity*, 0.2 for *fuel capacity*, 0.4 for *weigh/power ratio* and 0.1 for *dimension*. Note that weight indicates relative importance and therefore the numbers are only relatively meaningful. Also note that the weights could be normalised. In other words, the total weight of all factors associated with the same upper level attribute is summed to one. The weights in Figure 1 represent the customer's personal preference.

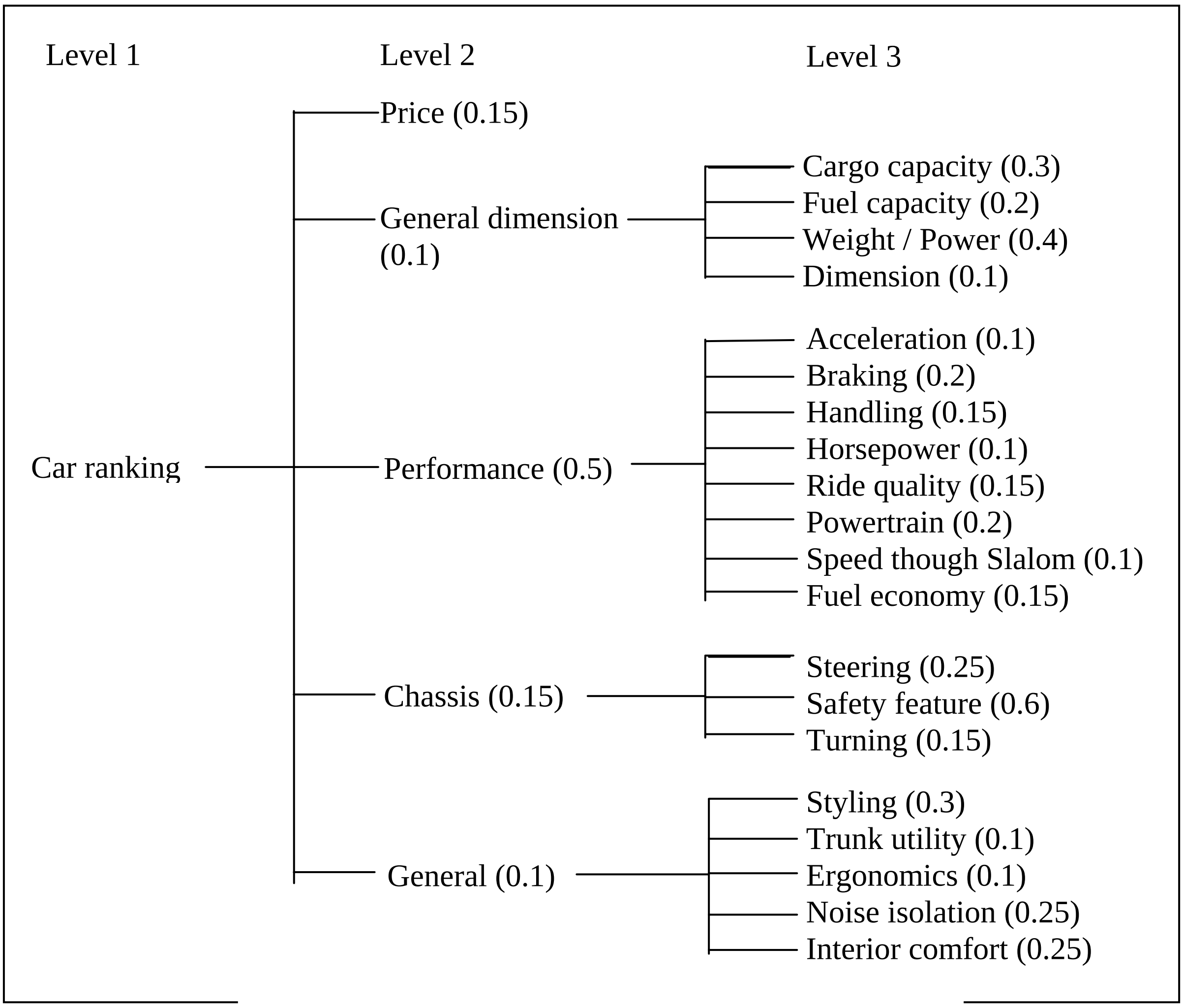

Figure 1 A Hierarchy of Factors for Car Selection

2.2 Performance Evaluation and Data Collection

The attributes shown in Figure 1 need to be defined and measured properly. Some of the attributes can be defined numerically and measured using numbers in certain units. For instance, *price* is defined as total purchasing price and measured in pounds. *Cargo capacity* is defined as the size of the luggage compartment measured in cubic feet. Other quantitative attributes include *fuel capacity, weight/power ratio, dimension, acceleration, braking, horsepower, fuel economy,* and *turning*. They can all be measured numerically.

Qualitative attributes are those difficult to measure by numbers in the first instance. They are normally evaluated using human judgements. *Powertrain*, for example, is related to the performance of an engine. It is evaluated on the basis of the quietness and smoothness of the engine. *Steering* is another qualitative attribute. It is related to the manoeuvrability of a car and is assessed based on the tightness and accuracy of steering. Other qualitative attributes include *handling, ride quality, speed through slalom, safety features, styling, trunk utility, ergonomics, noise isolation*, and *interior comfort*.

Data related to individual car evaluation could be collected from different sources such as magazines, motor show and World Wide Web. In this study, six cars are selected for analysis and they are ACURA 3.2TL Premium, BMW 325I, Infinity I30t, Lexus ES300, Mercedes Bens C280 and Mazda Mellenia S. The evaluation data were collected from BBC Top Gear Magazine, Motor Trend Performance Cars, Motor Show 1996 at the National Exhibition Centre in Birmingham, and World Wide Web sites for the manufacturers producing these cars. Table 1 shows the original assessment data collected for the six cars.

Table 1 Original Car Evaluation Data Collected

		Acura 3.2 TL Premium	BMW 3251	Infinity I30t	Lexus ES300	Mazda Mellenia	Mercedes Benz
Price ($)		36020	36420	34200	36453	33760	39332
Dimensions	Cargo cap.	14.1	10.3	14.1	14.3	13.3	13.7
	Fuel cap.	17.2	17.2	18.5	18.5	18.0	16.4
	Weight/power	17.6	16.7	16.9	18.0	16.2	17.0
	Dimension	12.23	10.47	12.06	11.61	11.90	11.04
Performance	Acceleration	8.8	8.0	7.7	8.4	8.0	7.9
	Braking	128	124	127	134	135	126
	Handling	B	A	B	B-	B+	A
	Horsepower	196	152	182	183	138	171
	Ride quality	A-	B-	B	B+	B+	A-
	Powertrain	B	B+	A	B	A-	A
	Speed th. Sla.	63.3	61.4	62.0	63.1	65.8	63.2
	Fuel economy	20	20	21	20	19	20
Chassis	Steering	B	A	B-	C+	B	A-
	Safety features	A	A	A	A	A	A+
	Turning	34.8	34.1	34.8	36.7	37.4	35.2
General	Styling	B-	B+	C-	B	A-	B+
	Trunk utility	A-	B-	A	B	B	B+
	Ergonomics	A	B-	B+	B+	B+	B+
	Noise isolation	B+	C+	B+	B+	B+	A-
	Interior comfort	A	B-	A-	B+	A-	B+

2.3 Model Building

Data in Table 1 are in different units and not ready for comparative analysis. They can be projected to the normalised utility space (4), (5) by defining utility grades, such as typical five grades named by E, A, B, C and P. The utilities of these grades may be given by u(E)=1, u(A)=0.8, u(B)=0.5, u(C)=0,2 and u(P)=0, respectively. The higher the utility of a grade, the better is the grade. The quantitative data and qualitative judgements may be transformed to the utility space using utility assessment methods (6).

A piecewise linear utility function could be established for a quantitative attribute by identifying the figures having the utilities of 1, 0.8, 0.5, 0.2 and 0. Take *price* for example. The acceptable *price* range is assumed to be between $30,000 and $40,000. This means that $30,000 is the lowest possible price and $40,000 the highest acceptable price. The utilities of

$30,000 and $40,000 are then assessed to one and zero, respectively. Suppose the utilities of $32,000, $35,000 and $38,000 are assessed to be 0.8, 0.5 and 0.2 respectively. Then, the utility of any other price between $30,000 and £40,000 may be calculated using a piecewise linear utility function (5).

Table 2 Equivalent Standardised Car Evaluation Data

		Acura 3.2 TL	BMW 3251	Infinity I30t	Lexus ES300	Mazda Mellenia	Mercedes Benz
Price ($)		C(0.34) B(0.66)	C(0.47) B(0.53)	B(0.73) A(0.27)	C(0.48) B(0.52)	B(0.59) A(0.41)	P(0.67) C(0.33)
Dimension	Cargo cap.	B(0.40) A(0.60)	P(0.75) C(0.25)	B(0.40) A(0.60)	B(0.27) A(0.73)	B(0.83) A(0.17)	B(0.60) A(0.40)
	Fuel cap.	C(0.33) B(0.67)	C(0.33) B(0.67)	A(0.85) E(0.15)	A(0.85) E(0.15)	B(0.43) A(0.57)	P(0.35) C(0.65)
	Weight/power	C(0.50) B(0.50)	B(0.73) A(0.27)	B(0.93) A(0.07)	C(0.83) B(0.17)	B(0.33) A(0.67)	B(1)
	Dimension	A(0.95) E(0.05)	C(0.43) B(0.57)	B(0.13) A(0.87)	B(0.50) A(0.50)	B(0.26) A(0.74)	B(0.97) A(0.03)
Performance	Acceleration	C(1)	C(0.23) B(0.77)	B(0.96) A(0.04)	C(0.63) B(0.37)	C(0.23) B(0.77)	C(0.13) B(0.87)
	Braking	B(0.67) A(0.33)	A(1)	B(0.50) A(0.50)	C(0.67) B(0.33)	C(0.83) B(0.17)	B(0.33) A(0.67)
	Handling	B(1)	A(1)	B(1)	C(0.33) B(0.67)	B(0.67) A(0.33)	A(1)
	Horsepower	A(0.25) E(0.75)	C(0.33) B(0.67)	B(0.07) A(0.93)	B(0.03) A(0.97)	C(0.93) B(0.07)	B(0.53) A(0.47)
	Ride quality	B(0.33) A(0.67)	C(0.33) B(0.67)	B(1)	B(0.67) A(0.33)	B(0.67) A(0.33)	B(0.33) A(0.67)
	Powertrain	B(1)	B(0.67) A(0.33)	A(1)	B(1)	B(0.33) A(0.67)	A(1)
	Speed through slalom	C(0.30) B(0.70)	P(0.10) C(0.90)	C(0.83) B(0.17)	C(0.37) B(0.63)	B(0.26) A(0.74)	C(0.33) B(0.67)
	Fuel economy	B(0.33) A(0.67)	B(1)	B(0.33) A(0.67)	C(0.33) B(0.67)	C(0.67) B(0.33)	C(0.33) B(0.67)
Chassis	Steering	B(1)	A(1)	B(0.67) A(0.33)	C(0.67) B(0.33)	B(1)	B(0.33) A(0.67)
	Safety features	A(1)	A(1)	A(1)	A(1)	A(1)	A(0.50) E(0.50)
	Turning	B(0.67) A(0.33)	B(0.33) A(0.67)	B(0.67) A(0.33)	C(0.57) B(0.43)	C(0.90) B(0.10)	B(0.87) A(0.13)
General	Styling	C(0.33) B(0.67)	B(0.67) A(0.33)	P(0.50) C(0.50)	B(1)	B(0.33) A(0.67)	B(0.67) A(0.33)
	Trunk utility	B(0.33) A(0.67)	C(0.33) B(0.67)	A(1)	B(1)	B(1)	B(0.67) A(0.33)
	Ergonomics	A(1)	C(0.33) B(0.67)	B(0.67) A(0.33)	B(0.67) A(0.33)	B(0.67) A(0.33)	B(0.67) A(0.33)
	Noise isolation	B(0.67) A(0.33)	C(0.67) B(0.33)	B(0.67) A(0.33)	B(0.67) A(0.33)	B(0.67) A(0.33)	B(0.33) A(0.67)
	Interior comfort	A(1)	C(0.33) B(0.67)	B(0.33) A(0.67)	B(0.67) A(0.33)	B(0.33) A(0.67)	B(0.67) A(0.33)

The utilities of qualitative attributes can also be assessed in a similar way. Take *handling* for example. The evaluation of *handling* may be classified into several categories. Without loss of generality and to simply the analysis, define five evaluation categories equivalent to the five utility grades. Suppose the utility grade E is equivalent to a *handling* evaluation category of "excellent control in cruising at high speed", A to "good control in cruising at high speed but soft wobbling felt sometimes", B to "good control but moderate wobbling felt sometimes", C to "average control and tight felt", and P to "difficult to control when cruising at high speed". By equivalent it is meant that the utility grade and the evaluation category in question have the same utility value. Since the number of evaluation categories for a qualitative attribute is limited, their utilities can be assessed using a utility assessment method.

Having obtained the utility values for all the data as shown in Table 1, the technique introduced in reference (6) may be employed to convert Table 1 to Table 2. The details about the conversion are available in reference (6).

The data displayed in Table 2 are equivalent to the corresponding ones shown in Table 1 in terms of utility equivalence. The data in Table 2 are organised in a consistent judgmental format. Take for example a quantitative attribute the *price* of Acura 3.2 TL Premium. It reads that the price of Acura 3.2 TL Premium is between the utility grades C and B with the degrees of belief of 0.34 and 0.66, respectively. The utility of this price is therefore equal to the following expected utility: $0.34u(C) + 0.66u(B) = 0.34\times0.2 + 0.66\times0.5 = 0.398$. On the other hand, the utility of the price \$36,020 was directly assessed to be 0.398.

A qualitative attribute is measured in a similar way in Table 2. For instance, the *ride quality* of Acura 3.2 TL Premium is between the utility grades B and A with the degrees of belief of 0.33 and 0.67. The utility of this judgement is therefore equal to: $0.33u(B) + 0.67u(A) = 0.34\times0.5 + 0.67\times0.8 = 0.701$. As shown in Table 1, the original judgement about the *ride quality* of Acura 3.2 TL Premium is A- whose utility was assessed to be 0.701.

Table 2 presents a decision model for the car selection problem. In this model, both quantitative data (numbers) and qualitative (subjective) judgements are measured in the same manner which is consistent and rational in terms of utility equivalence. Another feature of this model is that uncertain judgements can also be treated in the format without converting to certain numbers.

3. THE EVIDENTIAL REASONING APPROACH AND CAR SELECTION

3.1 Evidential Reasoning for Car Evaluation

The evaluation problem is to provide a clear ranking of these six executive cars for the customer on the basis of the evaluation hierarchy and weights shown in Figure 1 and the evaluation data given in Table 2 (or Table 1). This requires the rational synthesis of the evaluations of each car on all the 20 basic factors at level 3 in Figure 1, resulting in the propagation of the evaluations to the 5 attributes at level 2. The generated evaluations for the 5 attributes at level 2 are then combined to provide an assessment for each car. A ranking of the cars should result from such assessments. The difficulty in dealing with such a decision problem lies in the fact that both quantitative data and qualitative judgements need to be taken into account simultaneously and rationally.

The Evidential Reasoning (ER) approach provides a flexible yet rational way of dealing with such uncertain synthesis problems by means of evidence combination for multiple attributes. The ER approach can model the narrowing of individual evaluations and provide a combined distributive evaluation for each car. It can also generate a clear ranking for the cars based on the final expected utilities obtained. A brief description of the ER approach is provided in the rest of this section. More details about the ER approach can be found in references (2), (3), (4) and (6).

Suppose an attribute y_k is associated with L_k factors $e_1 \ldots e_i \ldots e_{L_k}$. Let H_n be the nth utility grade, H the whole utility space and N the number of utility grades defined. Define $m_{k,i}^n$ as a probability mass indicating the degree to which the ith factor e_i supports the hypothesis that the attribute y_k should be assessed to a utility grade H_n. $m_{k,i}^n$ can be generated from the given degrees of belief and weights (3), (4).

Let m_k^n be a probability mass measuring the degree to which y_k is evaluated to H_n. m_k^n is obtained by combining all factors associated with y_k. If $m_{I_k,(i+1)}^n$ is defined as the degree to which the first $(i+1)$ factors support the hypothesis that y_k should be assessed to a utility grade H_n, then $m_{I_k,(i+1)}^n$ can be generated using the following recursive evidential reasoning algorithm (3), (4)

$$\{H_n\}:\ m_{I_k(i+1)}^n = K_{I_k(i+1)}(m_{I_k(i)}^n m_{k,i+1}^n + m_{I_k(i)}^n m_{k,i+1}^H + m_{I_k(i)}^H m_{k,i+1}^n),\ n = 1, \cdots, N$$

$$\{H\}:\ m_{I_k(i+1)}^H = K_{I_k(i+1)} m_{I_k(i)}^H m_{k,i+1}^H$$

$$K_{I_k(i+1)} = \left[1 - \sum_{\tau=1}^{N} \sum_{\substack{j=1 \\ j\neq\tau}}^{N} m_{I_k(i)}^\tau m_{k,i+1}^j\right]^{-1}$$

$$i = 1, \cdots, L_k - 1$$

Note that in the above algorithm $m_{I_k,(1)}^n = m_{k,1}^n$ and $m_k^n = m_{I_k,(L_k)}^n$. Once m_k^n is obtained, the state of the attribute y_k can be evaluated in terms of the defined utility grades as follows

$$S(y_k) = \{(m_k^n,\ H_n),\ \text{for}\ n = 1, \cdots, \mathrm{N}\}$$

which means that the attribute y_k is evaluated to H_n with a degree of belief of m_k^n, $n=1, ..., N$.

3.2 Executive Car Selection

Applying the ER approach to combining the evaluations on the basic factors at level 3 leads to the combined evaluations of each car on the attributes at level 2, as shown in Table 3. A distributive evaluation is thus generated for each car on every attribute. By combining all the evaluations on the four basic factors at level 3, for example, the *general dimension* of Acura 3.2 TL Premium is assessed to utility grades C, B, A and E with the degrees of belief of 0.2578, 0.6438, 0.0655 and 0.0005, respective. This combined evaluation reads that the *general dimension* of Acura 3.2 TL Premium is to a large extent (more than 90%) assessed to the utility grades C and B. The rationale of this synthesis process is evident by looking at the relevant data in Table 2 and the relative weights of these four basic factors in Figure 1.

Table 3 Combined Evaluations at Level 2

	Acura	BMW 3251	Infinity	Lexus	Mazda	Mercedes

	3.2 TL Premium		I30t	ES300	Mellenia	Benz
Price ($)	C(0.3400) B(0.6600)	C(0.4700) B(0.5300)	B(0.7300) A(0.2700)	C(0.4800) B(0.5200)	B(0.5900) A(0.4100)	P(0.6700) C(0.3300)
Dimension	C(0.2578) B(0.6438) A(0.0655) E(0.0005)	P(0.0700) C(0.0524) B(0.7022) A(0.1340)	B(0.7062) A(0.2590) E(0.0040)	C(0.4985) B(0.2313) A(0.2135) E(0.0065)	B(0.4678) A(0.5087)	P(0.0073) C(0.0136) B(0.9324) A(0.0223)
Performance	C(0.0275) B(0.7812) A(0.1310) E(0.1447)	P(0.0026) C(0.0735) B(0.5159) A(0.3456)	C(0.0173) B(0.6083) A(0.3251)	C(0.1512) B(0.7743) A(0.0327)	C(0.2670) B(0.4685) A(0.2006)	C(0.0090) B(0.2766) A(0.6700)
Chassis	B(0.0200) A(0.9610)	B(0.0017) A(0.5240) E(0.4589)	B(0.0121) A(0.9723)	C(0.0153) B(0.0083) A(0.9554)	C(0.0061) B(0.0156) A(0.9573)	B(0.0096) A(0.5912) E(0.3825)
General	C(0.0717) B(0.4808) A(0.3985)	C(0.1345) B(0.7867) A(0.0468)	P(0.1483) C(0.1483) B(0.2279) A(0.3586)	B(0.9430) A(0.0395)	B(0.4720) A(0.4992)	B(0.7744) A(0.1996)

Table 4 Final Evaluations and Ranking of the Cars

	Acura 3.2 TL Premium	BMW 3251	Infinity I30t	Lexus ES300	Mazda Mellenia	Mercedes Benz
Evaluation	C(0.0299) B(0.7752) A(0.1419) E(0.0084)	P(0.0026) C(0.0704) B(0.5748) A(0.2840) E(0.0107)	P(0.0016) C(0.0116) B(0.5815) A(0.3603)	C(0.1392) B(0.7663) A(0.0502)	C(0.1626) B(0.4715) A(0.3082)	P(0.0143) C(0.0141) B(0.2983) A(0.6137) E(0.0080)
Expected utility	0.5378	0.5682	0.6039	0.4733	0.5437	0.6767
Ranking	5	3	2	6	4	1

Using the ER approach for the attributes at level 2, the evaluations shown in Table 3 can be further synthesised to generate a final evaluation for each car, as shown in the second row of Table 4. Such an evaluation takes into account both the original data of Table 1 and the customer’s weights of Figure 1 in a systematic way and thus provides a rational basis for generating a ranking of the cars.

An expected utility for each car is generated as the sum of the utility grades times the corresponding degrees of belief obtained, as shown in the third row of Table 4. The final ranking of the cars is produced on the basis of the magnitude of the final expected utilities generated.

As a result of this analysis, Mercedes Benz C280 is found to best suit the customer, as he preferred a high performance mid-sedan with good safety features. Infinity I30t is also a very good choice, followed by BMW 325I. The customer is advised not to choose Lexus ES300 if his preferences are properly represented by the weights shown in Figure 1.

4. CONCLUDING REMARKS

Real world assessment problems are often associated with both quantitative data and qualitative judgements of subjective nature. It is crucial to all the parties involved to synthesise different types of decision knowledge in order to arrive at a consensus view in a consistent and rational manner. The ER approach provides a general and flexible framework for such complex decision analysis. The application of the ER approach to the above executive car selection problem, as presented in this paper, shows its potential to help deal with a wide range of complex decision analysis problems of similar nature.

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