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ASSESSMENT OF MODAL TRANSPORTATION SUSTAINABILITY: APPLICATION OF DATA ENVELOPMENT AND CONCORDANCE ANALYSES*

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Abstract– This study tries to characterize national transportation modes to assess balancing and sustainability. Using a pioneer measure for sustainable development (SD), and based on the conformity of the growths of all sectors with transportation modes, the countries are comparatively studied. The proposed measure, elasticity, for each pair of variables indicates the extent to which the two variables have been changing consistently. Indeed the elasticity values are measures of "harmonic development" reflecting sustainability. The study database consisted of key aspects of transportation sustainability in the form of national variables including transportation, economic, social and environmental categories in the period 1980-1995. Having developed the elasticity of the social, environmental and economic variables with respect to those of modal transportation, composite modal sustainability indices were suggested. The composite indices were then integrated into a unique SD index utilizing the Data Envelopment Analysis (DEA), and Concordance Analysis (CA) techniques. For comparative appraisal, country ranking and grouping based on DEA scores, as well as CA results were developed. The sustainability appraisal showed interesting patterns within and between group similarities and differences. The study confirmed the significance of modal transportation balancing and sustainability challenges of the 21st century. The research focus is on its methodology. Thus, the data gathered from any other time period and geographical scope may be used for further analysis.

Keywords– Sustainable development, transportation modes, data envelopment analysis, transportation policy, comparative analysis

1. INTRODUCTION

The undesired impacts of transportation including congestion, safety, pollution and non-renewable resource depletion, are deeply intermingled with its key role in economic and social development. Most of the worlds' population lives in developing countries with inadequate transportation systems. Developed countries have limited resources to develop their systems further, but are facing having to make decisions to develop infrastructure toward more automobile support and reliance, or to focus on rail, bus, and bicycle infrastructures to give people more non-car choices [1].

The prevailing concern during the last forty years has been the undesirable socio-environmental impacts of population, urbanization and economic growth [2, 3]. The publication of "Our common future" known as the Brundtland Report, introduced sustainable development (SD) as a key concept addressing the intimate relationships between economic activities and ecology. The Brundtland Report acknowledges that the basic needs of all people should be met with due consideration of future generations [4].

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The concept of sustainable transportation is derived from these general terms that imply movement of people and goods in ways that are environmentally, socially and economically sustainable [5-7]. Nevertheless, there are numerous interpretations pertaining to sustainability, depending on the background and attitude of the researchers.

On the other hand, transportation modes have different operational and functional characteristics as well as dissimilar socio-economic and environmental impacts. Therefore, this paper has focused on these categories of transportation for the analysis. The main focus of this paper is to comparatively study sustainability with respect to transportation modes, i.e. air, road, rail, and sea, in a national scope.

The paper proposes a pioneer measure of sustainability, i.e. elasticity. It presents composite indices, and then measures the performances of the countries using the Data Envelopment Analysis (DEA) and Concordance Analysis (CA) based on which the countries are ranked.

2. DATA ENVELOPMENT ANALYSIS

DEA, occasionally called frontier analysis, is an increasingly popular management tool since it was first developed by Charnes *et al.* [8]. It is a methodology that has been used to evaluate the efficiency of entities (e.g., programs, organizations etc.), known as decision-making units (DMUs), which are responsible for utilizing resources to obtain outputs of interest. It has been used to evaluate activities as varied as public schools, hospital surgical units, and bank branches. It computes a scalar measure of efficiency and determines efficient levels of inputs and outputs for the organizations under evaluation.

Different models have been proposed in the context of DEA [9]. The DEA analysis can be either input-oriented or output-oriented. A process is called output-efficient if there is no other process in which using the same or a smaller amount of input produces a higher level of output. Conversely, a process is called input-efficient if there is no other process that in using the same or a higher amount of output produces a lower level of input [8-10]. In this paper, an input-oriented, variable return to the scale (VRS) model is chosen for the analysis. The following is the mathematical interpretation of the selected model. This model is solved for each DMU [9]

$$
\begin{aligned}
& Min\,\Phi \\
& \sum_j \lambda_j x_{jm} \le \Phi x_{j_0 m} && ; m = 1,2,\ldots,M \\
& \sum_j \lambda_j y_{jn} \ge y_{j_0 n} && ; n = 1,2,\ldots,N \\
& \lambda_j \ge 0 && ; j = 1,2,\ldots,J \\
& \sum_j \lambda_j = 1 && ; j = 1,2,\ldots,J
\end{aligned}
\tag{1}
$$

where x_{jm} is the m-th input of the j-th DMU, y_{jn} is the n-th input of the j-th DMU, Φ is the efficiency of each DMU, and λ_j is the model variables representing the weight of each DMU.

3. CONCORDANCE ANALYSIS

CA is one of the multi-criteria assessment tools in which alternative plans are ranked by a series of pairwise comparisons across a set of objectives in a rank-ordering technique. In the current study, the alternatives are countries and objectives are calculated indices. The analysis is based on the project effects matrix, which contains a vector of scores for each alternative on each of the chosen objective measures. Two different indices are calculated from the project effects matrix: A concordance index calculates the degree to which one alternative plan is preferred to another for a given weighting structure on the objectives. A discordance index calculates the degree to which one alternative plan is dominated by another. Dominance indices are developed from the concordance and discordance scores, and are used to establish the relative preference of each alternative with respect to the given weighting scheme. Alternatives that perform better than average on both concordance and discordance are defined as non-dominated [11].

Let Zij be the raw value of the jth index for the ith country, shown in Table 3. Let r_{ij} be the normalized value of the jth index for the ith country. Then

$$r_{ij} = \begin{cases} \dfrac{Z_{ij}}{\max\limits_{k} Z_{ik}} & \text{if greater values of } Z_{ij} \text{ are desirable} \\ 1 - \dfrac{Z_{ij}}{\max\limits_{k} Z_{ik}} & \text{if smaller values of } Z_{ij} \text{ are desirable} \end{cases} \tag{2}$$

The concordance and discordance sets are defined as

$$C_{ii'} = \{j \mid r_{ij} \geq r_{i'j}\} \tag{3}$$

$$D_{ii'} = \{j \mid r_{ij} < r_{i'j}\} \tag{4}$$

respectively*, in which i and i' are a pair of countries whose r indices are being compared*. The concordance and discordance indices are respectively defined as

$$c_{ii'} = \sum_{j \in C_{ii'}} w_j \quad \forall i \neq i' \tag{5}$$

$$d_{ii'} = \frac{\sum\limits_{j \in D_{ii'}} \left\{ \dfrac{w_j \left| r_{ij} - r_{i'j} \right|}{d^{\max}} \right\}}{m} \tag{6}$$

where w_j is the weight given to the jth elasticity index, and

$$d^{\max} = \max_{\substack{i,i' \\ j}} w_j \left| r_{ij} - r_{i'j} \right| \tag{7}$$

$$m = \max_{i,i'} \{\text{number of elements in } D_{ii'}\} \tag{8}$$

Finally, the net concordance dominance and net discordance dominance values are

$$c_i = \sum_{i \neq i'} c_{ii'} - \sum_{i \neq i'} c_{i'i} \tag{9}$$

$$d_i = \sum_{i \neq i'} d_{ii'} - \sum_{i \neq i'} d_{i'i} \tag{10}$$

Countries with $c_i > 0$ and $d_i < 0$ may be considered non-dominant. These are the better countries given the set of index weights. (For further details regarding the above notations, the interested reader may refer to [11]).

4. ELASTICITY AS A MEASURE OF SUSTAINABILITY

Although there is no unified definition and interpretation of sustainability, most studies have the common feature of quantifying it by the indicators that are related to the three key dimensions of social, environmental and economic [12-20]. To address some of the pertinent sustainability issues, in this paper a comparative macroscopic assessment of modal transportation at the national level was conducted from economic, environmental and social perspectives. In order to be able to perform such an assessment, one way to measure this manifold concept is redefining the popular term "sustainable development" as "harmonic development". This interpretation is applicable because consistency among the changes of all of these three aspects, as well as transportation modes would naturally cause SD. The current research proposes a measure of sustainability based on this special viewpoint. This measure is elasticity, which has been borrowed from the economics.

Elasticity is used as a technique for developing indicators that are more comprehensive. The basic idea of "elasticity" is that it measures how strongly people respond to a change in a relevant factor [21]. For instance, when the demand for a product is price elastic, then the quantity demanded changes significantly when the price of the product changes. Conversely, when the demand is price inelastic, then the quantity demanded changes only a little when the price changes. Elasticity is widely used in economic analyses that study the relationship between the price of a commodity and its demand. In such analyses, depending on the elasticity values, demand can be elastic or inelastic. Indeed, elasticities greater than 1 indicate an elastic relationship and those less than one reflect an inelastic relationship [7]. In the current paper, which comparatively studies the relationship between social, environmental, and economical variables as well as modal transportation variables, the ordinal values of elasticity among countries are important and are used to assess the sustainable transportation of the countries.

Elasticity has limitations and strengths. It measures economic, environmental, or social change with respect to transportation change and therefore is a trend variable [21]. This characteristic also implies that elasticity reflects the relative dynamic behavior of the variables. The term "relative" herein means that elasticity shows the trends of variables but does not reflect their state.

5. DATABASE

In order to assess the sustainability or balancing of transportation modes at a national level, the relevant time-series of transportation, social, environmental, and economic information was gathered and analyzed. The main encountered problem was the availability and accessibility to comparable relevant transportation data on demand, supply, utilization and impacts at the national level. A few past studies have attempted such a comparative assessment, but have mostly addressed the issues qualitatively [3]. After evaluation of the centralized and accessible time-series databases and their completeness, the limited study resources confined the selected countries to approximately two thirds across the globe.

The preliminary evaluation of the accessible centralized databases covered the three decades over a period from 1970 to 2000 for more than 190 countries. The initially collected relevant national indicators included more than 450 variables encompassing categories of transportation, demographics, economics, social, environmental, geographical and political [22-24].

Due to many missing data, it was necessary to find a subset of variables presenting key dimensions of sustainability. By using factor analysis and a cut-off rule for the minimum number of non-missing data, the number of variables in each group was significantly reduced. Due to data incompleteness and study resource limits, the final study database was confined to 39 variables for 42 countries. The reliability of the database was checked as much as possible when the respective governments had reported the data to international agencies. The selected variables reflected the major required dimensions. The selected 42 countries covered four continents and met minimum data requirements. They were 18 in Europe, 14 in Asia, 7 in America, and 3 in Africa.

The process of data refinement and reduction included several stages of univariate and multivariate statistical analyses as well as data availability considerations. The variables were then reduced using the results of factor analysis. The selected variables were the most correlated variables with the factors computed by the principal component method and Varimax rotation in the SPSS package.

In order to reflect transportation relationships and impacts on non-transportation variables, ideally, those that were most influenced by transportation should have been selected. For some of the selected variables, such as energy consumption in the environmental group, the relationships are intuitive. For some of the other variables such as hospital beds in the social group, the existence of a direct relationship is questionable and vague. After the evaluation of more than 450 variables in the initial database, it was decided that social, environmental and economic groups should be presented in order to reflect the three key dimensions of sustainability. Harmonization of development in any of the key dimensions with respect to transportation development is desirable and hints towards SD, even if the direct relationship is perceived as fuzzy or questionable.

The final database was comprised of 21 variables in the transportation group and 6 variables for each of the three groups of economy, social aspect, and environment. The time scope of detail assessment covered the period of 1980-1995, when due to many missing data, other periods of 1970-1980 and 1995-2000 were excluded for further analysis. Table 1 shows the final study database structure and variables. The variable names consisted of 4 characters. The first character reflects the group membership; the remaining 3 characters reflect the variable description. The last character in the transportation variables reflects the mode.

The univariate statistical analysis of the database illustrates the database cross-sectional and time-series variability. The analysis covered the computation of statistics such as minimum, maximum, mean, standard deviation and coefficient of variation. Table 2 shows the mean and coefficient of variation values of the selected variables for the years 1980 and 1995. For both 1980 and 1995, the coefficients of variation in descending order belonged to air transportation, environmental, rail transportation, road transportation, economic, seaborne transportation, and social variables, respectively.

In order to develop an understanding of the interrelationship among the database variables pair-wise correlation analysis for both years of 1980 and 1995 was performed. The size of two 39x39 correlation matrices prevented their display herein. The resulted matrices revealed a number of interesting patterns and were found useful in the elasticity analysis phase of the study. Many pairs of variables were found correlated at a level of significance, 0.05.

6. ELASTICITY ANALYSIS

The preferred measure of the relationship is the proportional or percent change in the variables that is also dimensionless. It is often used for large systems studies with enormous variables when the cause and effect relations are complex and vague. Elasticity gives simple and interpretable results for any type of data, irrespective of dimensionality and/or causality. The arc elasticity E of a variable Y with respect to a variable X for the period t1-t2 shows that the percent variable Y changes with respect to a one percent change of the variable X as is shown by Eq. (1)

$$E_{Y/X,\,t1\text{-}t2} = E_{Y/X} = \frac{\left(\dfrac{Y_{t2} - Y_{t1}}{Y_{t2} + Y_{t1}}\right)}{\left(\dfrac{X_{t2} - X_{t1}}{X_{t2} + X_{t1}}\right)} \tag{11}$$

Where $E_{Y/X,t1\text{-}t2}$ is the arc elasticity of variable Y with respect to variable X during the period t1 to t2. As the period of t1-t2 gets smaller and converges to zero, the arc elasticity converges to point elasticity.

Table 1. Description and structure of the database variables

Variable	Category	Description	Dimension
TIPA	Air	International passenger kilometers	Millions
TITA	Air	International total tons-kilometers	Millions
TTPA	Air	Total - passenger kilometers	Millions
TTTA	Air	Total tons-kilometers	Millions
TIKA	Air	International kilometers flown	Millions
TTKA	Air	Total kilometers flown	Millions
TPKR	Rail	Passengers - kilometers	Million
TTKR	Rail	Railway ton-km	Million ton-km
TLRR	Rail	Length of railway lines	Km
TNGR	Rail	Number of goods wagons	#
TNLR	Rail	Number of locomotives	#
TNPR	Rail	Number of passenger coaches	#
TGTH	Road	Goods transported	Million ton-km
TTWH	Road	Two-wheelers	Per 1,000 people
TCVH	Road	Commercial vehicles in use	Thousand units
TNBH	Road	Number of buses and coaches	1000#
TPCH	Road	Passenger cars in use	Thousand units
TTNH	Road	Total network	km
TGLS	Sea	Goods loaded in international sea-born	Million ton
TGUS	Sea	Goods unloaded in international sea-born	Million ton
TIPS	Sea	Incoming passengers in international sea-born	1000 pass
TOPS	Sea	Outgoing passengers in international sea-born	1000 pass
TTGS	Sea	Total goods in international sea-born	1000 ton
SLEX	Social	Life expectancy	Years
STLF	Social	Total labor force	Thousand persons
SUPN	Social	Urban population	% Total population
SSWR	Social	Safe water	% Population with access
SHBD	Social	Hospital beds	Per thousand people
SAIR	Social	Adult illiteracy rate	% People age 15+
EALD	Environment	Arable land	Thousand hectares
ECEU	Environment	Commercial energy use	Tons
ETEU	Environment	Total energy use	Thousand tons
ELAR	Environment	Land area	Thousand hectares
ECO2	Environment	CO2 emissions	Thousand tons
ETEP	Environment	Total energy production	Thousand tons
CTEX	Economic	Total expenditure	% GDP
CGDP	Economic	GDP	Million US$
CCIN	Economic	Consumer inflation consumer prices	Annual %
CIPM	Economic	Interest payments	% total expenditure
CTCN	Economic	Total consumption	Million US$
CTML	Economic	Telephone mainlines	Per thousand people

In order to assess sustainability comparatively, elasticities of non-transportation variables with respect to transportation variables were computed. They reflected the elasticity of the social, environmental and economic variables with respect to passenger or freight transportation variables. In the absence of any perceived and intuitive causal relationships between transportation and social, environmental and economic variables, sustainability is deemed to be characterized by a manifold growth or diminishment, depending on the nature of variables in harmony and consistency with transportation growth. In this part, the elasticity of 6 social variables, SLEX to SAIR, 6 environmental variables, EALD to ETEP, and 6 economic variables, CTEX to CTML, with respect to the 21 transportation variables were studied. In the absence of an intuitive relation, elasticity was still found acceptable to reflect the harmony or disharmony between two variables over a period of time.

Table 2. Descriptive analysis of the database for years 1980 and 1995

Variable	Mean 1980	Coefficient of variation 1980	Mean 1995	Coefficient of variation 1995	% Mean change based on 1995*
TITA	1090.8	1.90	3257.0	1.94	66.51
TTTA	2152.5	3.42	5346.2	2.96	59.74
TIPA	2734.0	1.77	21679.6	1.99	87.39
TTPA	12511.9	3.65	41301.2	3.22	69.71
TIKA	60.3	1.67	144.1	1.79	58.15
TTKA	181.6	3.77	351.3	3.61	48.32
TTNH	168128.5	1.74	226321.4	1.75	25.71
TGTH	46167.4	1.94	54342.4	1.92	15.04
TCVH	1076.4	2.15	1757.7	1.98	38.76
TNBH	76.4	1.64	145.4	1.60	47.45
TTWH	26.8	1.56	41.6	1.15	35.61
TPCH	3498.2	1.67	5247.1	1.79	33.33
TTKR	53796.9	3.94	35142.8	2.83	-53.08
TPKR	21421.0	2.65	27788.3	2.82	22.91
TLRR	11221.1	1.67	10096.1	1.57	-11.14
TNLR	1318.8	1.37	1115.3	1.44	-18.24
TNGR	26384.5	1.26	19355.2	1.49	-36.32
TNPR	3446.8	1.63	3050.9	1.82	-12.98
TMSS	5637.3	1.75	4127.2	1.52	-36.59
TGLS	49.5	1.29	87.2	1.02	43.21
TGUS	76.9	1.58	125.9	1.50	38.89
ECO2	66820.3	2.86	83235.5	2.63	19.72
ETEU	86384.6	3.00	119713.4	2.75	27.84
ETEP	80055.5	2.97	111732.3	2.47	28.35
EALD	16326.1	2.31	16737.6	2.26	2.46
ECEU	92.1	3.03	122.0	2.65	24.50
ELAR	114.2	1.99	114.2	1.99	0.00
SAIR	29.1	0.79	19.5	1.00	-49.06
SHBD	5.3	0.86	4.6	0.82	-16.29
STLF	23045.0	2.10	30684.6	2.11	24.90
SLEX	66.8	0.12	71.6	0.08	6.68
SSWR	71.9	0.35	92.5	0.32	22.26
SUPN	56.1	0.39	62.2	0.34	9.83
CTEX	28.8	0.40	31.1	0.41	7.62
CGDP	254632.9	2.58	375972.8	2.54	32.27
CCIN	18.3	0.99	13.3	1.45	-37.22
CIPM	7.7	0.52	14.6	0.64	47.16
CTML	151.1	1.06	263.7	0.86	42.69
CTCN	200174.7	2.61	302160.2	2.57	33.75

* % mean change based on 1995=100* (mean 1995 –mean 1980)/mean 1995

For each country, based on non-missing values, a maximum of 378 elasticities for the period of 1980-1995 were computed. For Eq. (1), Y's were SLEX to SAIR, EALD to ETEP, and CTEX to CTML, and X's were passenger or freight variables. Study of individual elasticities revealed a number of interesting patterns. Each country was characterized by a profile consisting of 378 measures hinting at different dimensions for SD with respect to the 21 transportation variables. To support sustainability, reductions of non-transportation variables SAIR, ECEU, ETEU, ECO2, CTEX, CCIN and CTCN were found more desirable, irrespective of transportation variables lessening or growth. The developed arc elasticities provided dimensionless and acceptable measures to assess changes for pairs of non-transportation and transportation variables during the period 1980 to 1995. They encompassed key SD dimensions of social, environmental and economic variables with corresponding transportation variables. Each of the developed elasticities represented a unique facet hinting at SD, harmony and balancing. They were found to be acceptable indicators for sustainability appraisal addressing specific subjects pertinent to the involved pairs of variables. The developed elasticities offered a profile for each country consisting of 378 indicators. Nevertheless, space limitation prohibited their display herein.

Table 3. Sustainability indices

No.	Country	SI_{TAIR}	SI_{TROD}	SI_{TRAL}	SI_{TSEA}	No.	Country	SI_{TAIR}	SI_{TROD}	SI_{TRAL}	SI_{TSEA}
1	Austria	-0.02	-0.01	0.00	0.11	40	South Korea	0.06	0.03	-0.06	-0.02
2	Bangladesh	-0.02	-0.01	0.09	-0.03	41	Malaysia	-0.03	-0.02	0.03	-0.04
3	Belgium	-0.02	-0.01	-0.25	-0.07	42	Morocco	-0.02	-0.02	0.04	0.14
4	Brazil	-0.03	-0.01	0.11	-0.02	43	Netherlands	-0.23	0.35	-0.03	-0.01
5	Bulgaria	0.03	0.07	-0.01	-0.24	44	Norway	-0.03	0.03	-1.63	-0.03
6	Burma	-0.07	-0.01	0.02	-0.06	45	Pakistan	-0.03	-0.03	0.02	-0.07
7	Canada	-0.02	-0.01	0.03	-0.08	46	Peru	0.00	0.01	0.00	-0.08
8	Chile	-0.03	0.33	0.00	0.08	47	Philippines	-0.03	-0.04	0.03	-0.07
9	Denmark	0.52	0.09	0.10	0.59	48	Poland	-0.15	0.05	0.01	-0.02
10	Ecuador	-0.02	0.00	0.03	-0.06	49	Portugal	-0.05	-0.03	0.06	-0.06
11	Egypt	-0.01	-0.01	0.04	-0.05	50	Saudi Arabia	-0.02	-0.01	0.07	-0.12
12	Finland	-0.06	-0.05	-0.30	-0.04	51	Spain	-0.04	0.13	0.06	-0.06
13	France	-0.01	-0.02	0.52	-0.07	52	Sri Lanka	-0.02	-0.02	-0.09	-0.02
14	Greece	0.01	-0.02	0.06	-0.11	53	Sweden	-0.23	-0.10	-0.06	-0.03
15	Hungary	0.02	0.07	0.01	-0.05	54	Syria	1.19	0.03	0.07	-0.04
16	India	-0.03	-0.03	0.02	-0.02	55	Thailand	-0.08	-0.09	0.04	-0.07
17	Indonesia	-0.03	-0.04	0.03	-0.02	56	Tunisia	-0.01	0.08	0.07	0.00
18	Iran	-0.08	0.14	0.02	-0.06	57	Turkey	-0.04	-0.02	0.10	-0.06
19	Ireland	-0.09	-0.05	0.06	0.66	58	United Kingdom	-0.20	-0.09	0.27	-0.03
20	Italy	-0.03	-0.02	0.04	-0.07	59	United States	-0.06	-0.09	-0.02	-0.05
21	Japan	-0.02	0.00	0.06	-0.07	60	Venezuela	0.04	-0.05	0.01	-0.21

7. AGGREGATING INDIVIDUAL ELASTICITIES

Each of the computed elasticities is a single dimension addressing a particular aspect of the system sustainability. Having measured individual indicators, their aggregation has been suggested to reflect the overall system status. The developed composite indices often are not so intuitive to interpretation; nevertheless, they reflect all-inclusive measures. They are needed for overall comparative appraisal and benchmarking.

The development of 378 elasticities made a base available to develop composite sustainability indices. The idea behind the concept of sustainability, as discussed earlier, emphasizes the multi-dimensionality of issues and keeps a balanced focus on the changes of key dimensions. Consequently, the individual elasticities were aggregated for a single overall measure that contained information from all dimensions. The developed aggregate measures of elasticities with respect to transportation modes reflected the extent to which all aspects have comparatively changed with respect to changes in the transportation mode status. The developed composite index for each transportation variable demonstrated how harmonized the country has, overall, grown with respect to passenger or freight transportation. There are many suggestions to combine different sustainability indicators in order to develop a single measure to present the approximate overall status [25, 26]. As social, environmental and economic aspects are the major dimensions of sustainability, for each group an aggregate measure was developed. To make elasticities comparable, Z scores were computed by the following equation:

$$ZE_{Y/X} = \frac{E_{Y/X} - M(E_{Y/X})}{S(E_{Y/X})} \tag{12}$$

Where $ZE_{Y/X}$ is the Z score of the $E_{Y/X}$ as computed by Eq. (11), and M and S are functions that provide the mean and the standard deviation of their arguments, respectively. The composite index CI for each of the social, environmental and economic groups was computed using the Z scores

$$CI_{G/X} = \frac{\sum \alpha_Y ZE_{Y/X}}{\sum |\alpha_Y|} \tag{13}$$

Where $CI_{G/X}$ is the composite index of group G, either social, S group, environmental, E group, or economic, C group, with respect to transportation group X, either passenger, U, or freight, D. α_Y's are coefficients that are +1 for elasticities with a desirable positive sign and -1 for those with a desirable negative sign when the Y variable is SAIR, ECEU, ETEU, ECO2, CTEX, CCIN and CTCN, and $|\alpha_Y|$ is the absolute value of α_Y. To develop an overall sustainability index, social, environmental and economic composite indices were again aggregated as a weighted combination

$$SI_X = (\beta_S\, CI_{S/X} + \beta_E\, CI_{E/X} + \beta_C\, CI_{C/X}) / (\beta_S + \beta_E + \beta_C) \tag{14}$$

Where SIX is the sustainability index of the transportation group X, and βS, βE and βC are the weighting factors of social, environmental and economic dimensions, respectively. Table 3 shows the results of the above-mentioned computations using equal weighting factors βS = βE = βC. Based on Z score computation and usages, as reflected by Eq. (12), the negative values for the sustainability index should be interpreted in the context of comparative assessment.

In the context of SD, the larger composite index values reflected the comparatively preferred overall social, economic and environmental developments with respect to transportation development. The composite indices showed the overall harmony and uniformity between non-transportation groups on the one hand, and each transportation variable on the other hand. In this respect, Table 3 shows the overall comparative sustainability situation of countries. Countries with higher indices are comparatively more sustainable. Although each country is unique due to its inherent characteristics, history and background, it can learn about sustainability from others. Countries with high scores can be used as showcases for good practice and experience sharing.

8. THE DEA RESULTS

In this stage, DEA is utilized to achieve an overall score for each country. In this study, countries are DMUs, the database variables in the year 1980 are inputs, and four composite indices are outputs. The computed scores reflect the countries' performances with respect to Modal Transportation Sustainability and thus is an index of comprehensive sustainability.

Figure 1 schematically illustrates an efficient frontier for the simplified case of two output and one input. In this figure, the broken line connects the countries with the best efficiency (i.e. the best combination of output input ratios). Table 4 shows the results of DEA for the selected countries (DMUs). The column titled "score" in the table shows the efficiency scores of countries based on their performance in creating composite indices of transportation modes. The countries with 100 percent scores are those in the frontier based on inputs and outputs. "Benchmarks" column in the table, for efficient DMUs, shows the number of inefficient ones which, in achieving their best practices, use current DMU's information, and for inefficient DMUs show the target efficient ones which could serve as the best practices of the current case.

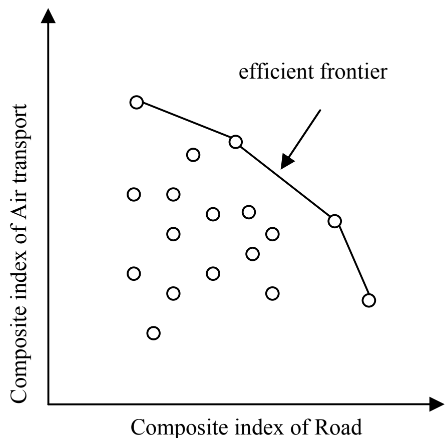

Fig. 1. The efficient frontier with respect to only two composite indices

Table 4. The efficiency scores and benchmarks based on the DEA results

	DMU	Score	Benchmarks		DMU	Score	Benchmarks
1	Austria	1.00	0	22	South Korea	1.00	4
2	Bangladesh	1.00	17	23	Malaysia	0.67	2 (0.05) 38 (0.92)
3	Belgium	0.53	2 (0.59) 4 (0.04) 36 (0.03) 38 (0.16)	24	Morocco	0.83	10 (0.14) 19 (0.23) 36 (0.01) 38 (0.62)
4	Brazil	1.00	4	25	Netherlands	0.40	2 (0.20) 4 (0.03) 38 (2.49)
5	Bulgaria	0.92	8 (0.03) 22 (0.17) 34 (0.05) 36 (0.03) 38 (0.72)	26	Norway	0.25	19 (0.02) 36 (0.38) 38 (0.49)
6	Burma	1.00	9	27	Pakistan	0.42	2 (0.33) 38 (0.64)
7	Canada	0.08	10 (0.77) 36 (0.00) 38 (0.22)	28	Peru	1.00	0
8	Chile	1.00	2	29	Philippines	0.47	10 (0.84) 38 (0.16)
9	Denmark	1.00	0	30	Poland	0.31	2 (0.11) 22 (0.17) 34 (0.13) 38 (0.58)
10	Ecuador	1.00	5	31	Portugal	0.39	2 (0.36) 38 (0.63)
11	Egypt	0.47	2 (0.60) 36 (0.01) 38 (0.37)	32	Saudi Arabia	0.72	10 (0.54) 42 (0.74)
12	Finland	0.30	6 (0.08) 19 (0.02) 34 (0.02) 36 (0.00) 38 (0.66)	33	Spain	0.11	2 (0.12) 4 (0.00) 38 (1.23)
13	France	0.06	2 (0.28) 6 (0.18) 34 (0.09) 38 (0.72)	34	Sri Lanka	1.00	11
14	Greece	0.53	10 (0.10) 36 (0.02) 38 (0.89)	35	Sweden	0.18	6 (0.10) 34 (0.07) 38 (0.77)
15	Hungary	1.00	0	36	Syria	1.00	9
16	India	0.10	2 (0.28) 6 (0.02) 22 (0.10) 34 (0.63)	37	Thailand	0.49	2 (0.29) 38 (0.69)
17	Indonesia	0.15	2 (0.02) 6 (0.00) 34 (0.01) 38 (0.95)	38	Tunisia	1.00	23
18	Iran	0.90	6 (0.51) 8 (0.41) 34 (0.01) 38 (0.07)	39	Turkey	0.76	2 (0.64) 6 (0.19) 34 (0.16) 38 (0.04)
19	Ireland	1.00	3	40	United Kingdom	0.05	2 (0.14) 38 (0.97)
20	Italy	0.08	2 (0.37) 6 (0.24) 34 (0.04) 36 (0.00) 38 (0.35)	41	United States	0.52	2 (0.31) 4 (0.62)
21	Japan	0.03	2 (0.63) 6 (0.14) 22 (0.19) 34 (0.05)	42	Venezuela	1.00	1

9. THE CA RESULTS

Performing the CA calculations for the 42 countries and 4 composite elasticity indices with 5 weighting strategies identifies the comparative situation of countries with respect to transportation sustainability and balancing. The 5 weighting strategies are: giving equal emphasis to all indices as weighting system number 1, and giving more emphasis to air transport, road transport, rail transport, and maritime transport groups as weighting systems numbers 2 to 5, respectively. Table 5 shows the values for these different weighting systems. Table 6 shows the results of the calculation of net concordance and net discordance indices for the countries and considering the weighting systems introduced. The last two columns in the table are the difference between a country's NCI and NDI (DCD), and the number of non-dominance in each weighting system, respectively. The greater the number of countries' non-dominance are, the better they are.

Table 5. Weighting systems in CA

weighting system	Weights of each index			
	SI_{TAIR}	SI_{TROD}	SI_{TRAL}	SI_{TSEA}
w1	*0.25*	*0.25*	*0.25*	*0.25*
w2	*0.40*	*0.20*	*0.20*	*0.20*
w3	*0.20*	*0.40*	*0.20*	*0.20*
w4	*0.20*	*0.20*	*0.40*	*0.20*
w5	*0.20*	*0.20*	*0.20*	*0.40*

Table 6. CA results

Countries	Net discordance index (NDI) in weighting system:					Net concordance index (NCI) in weighting system:					Average NCI-NDI (DCD)	No. of non-dominance
	w1	w2	w3	w4	w5	w1	w2	w3	w4	w5		
Austria	-0.93	-0.37	-0.21	-0.55	-1.18	4.50	4.20	3.80	-0.60	10.60	5.15	4
Bangladesh	0.04	0.08	0.22	-0.30	0.09	18.25	18.40	16.80	20.80	17.00	18.23	1
Belgium	2.22	1.18	1.33	1.63	1.41	-7.50	-3.00	-4.60	-13.00	-9.40	-9.05	0
Brazil	0.04	0.13	0.26	-0.33	0.04	13.50	8.60	11.80	18.20	15.40	13.47	1
Bulgaria	0.94	0.34	-0.19	0.40	1.79	-1.00	5.80	4.60	-5.40	-9.00	-1.66	1
Burma	1.35	0.95	0.93	0.53	0.96	-10.50	-13.80	-7.80	-9.00	-11.40	-11.45	0
Canada	1.22	0.67	0.92	0.46	1.01	-5.00	-0.60	-4.60	-4.20	-10.60	-5.85	0
Chile	-8.56	-4.17	-8.03	-4.37	-4.83	11.50	7.80	17.00	5.40	15.80	17.49	5
Denmark	-13.39	-8.60	-7.65	-7.03	-10.20	36.50	37.00	35.80	36.20	37.00	45.88	5
Ecuador	0.73	0.44	0.55	0.19	0.63	5.00	6.20	6.60	5.40	1.80	4.49	0
Egypt	0.55	0.31	0.49	0.09	0.49	10.00	13.00	9.80	9.80	7.40	9.61	0
Finland	3.35	1.90	2.35	2.31	1.82	-21.00	-21.80	-22.60	-24.20	-15.40	-23.35	0
France	-1.13	-0.51	-0.15	-1.91	-0.24	6.50	9.80	2.20	13.40	0.60	7.29	5
Greece	1.24	0.59	0.97	0.38	1.16	2.00	7.40	0.20	5.80	-5.40	1.13	0
Hungary	-1.39	-0.76	-1.40	-0.80	-0.51	11.50	15.40	15.00	6.20	9.40	12.47	5
India	1.02	0.61	1.00	0.37	0.57	-3.50	-3.40	-7.40	-3.80	0.60	-4.21	0
Indonesia	1.12	0.65	1.13	0.39	0.61	0.00	0.20	-5.00	1.00	3.80	-0.78	0
Iran	-2.07	-0.73	-2.49	-1.17	-0.78	-2.00	-7.80	5.80	-3.00	-3.00	-0.55	1
Ireland	-6.20	-2.78	-2.34	-3.34	-7.03	-1.50	-7.80	-7.80	2.60	7.00	2.84	2
Italy	1.29	0.76	1.02	0.45	0.99	-9.50	-10.20	-9.80	-4.60	-13.40	-10.40	0
Japan	0.66	0.40	0.51	0.08	0.64	7.00	7.40	8.60	10.20	1.80	6.54	0
Korea, South	-0.77	-0.59	-0.63	-0.33	-0.38	13.50	18.20	15.00	5.00	15.80	14.04	5
Malaysia	1.02	0.61	0.91	0.36	0.67	-2.00	-1.80	-4.20	-1.40	-0.60	-2.71	0

Table 6 Continued.

Morocco	-1.29	-0.56	-0.27	-0.84	-1.56	11.50	10.20	7.40	11.80	16.60	12.41	5
Netherlands	-6.43	-2.38	-7.20	-3.24	-3.25	1.00	-7.00	9.00	-4.60	6.60	5.50	3
Norway	7.63	3.93	3.55	7.72	3.89	-3.00	-4.20	2.20	-10.60	0.60	-8.34	0
Pakistan	1.58	0.91	1.27	0.66	1.11	-16.50	-16.20	-17.40	-15.00	-17.40	-17.61	0
Peru	0.64	0.32	0.38	0.23	0.68	-1.00	4.60	2.60	-4.20	-7.00	-1.45	0
Philippines	1.73	0.97	1.45	0.70	1.20	-14.00	-12.20	-16.60	-10.60	-16.60	-15.21	0
Poland	0.14	0.63	-0.32	-0.04	0.08	1.00	-6.20	5.80	-1.80	6.20	0.90	1
Portugal	1.33	0.86	1.11	0.42	0.94	-7.00	-9.80	-9.40	-0.60	-8.20	-7.93	0
Saudi Arabia	1.43	0.80	1.01	0.45	1.32	-0.50	1.00	-0.60	5.40	-7.80	-1.50	0
Spain	-2.33	-1.00	-2.51	-1.40	-0.92	7.00	1.80	12.60	9.00	4.60	8.63	5
Sri Lanka	1.20	0.67	0.95	0.73	0.64	-1.00	1.80	-1.80	-7.40	3.40	-1.84	0
Sweden	4.52	3.12	3.53	2.32	2.33	-25.25	-28.40	-28.40	-26.40	-17.80	-28.41	0
Syria	-3.42	-6.10	-1.88	0.97	-1.55	6.00	13.00	8.60	-3.00	5.40	8.40	4
Thailand	3.15	1.86	2.73	1.39	1.91	-19.50	-21.40	-22.60	-13.40	-20.60	-21.71	0
Tunisia	-2.11	-1.00	-1.80	-1.32	-1.16	27.50	26.20	28.20	27.40	28.20	28.98	5
Turkey	0.97	0.62	0.91	0.16	0.75	-2.50	-5.40	-5.40	4.60	-3.80	-3.18	0
United Kingdom	2.49	1.97	2.42	0.51	1.32	-6.50	-12.60	-12.60	2.60	-3.40	-8.24	0
United States	3.22	1.84	2.83	1.57	1.82	-22.00	-22.20	-25.40	-22.60	-17.80	-24.25	0
Venezuela	3.22	1.45	2.36	1.50	2.74	-11.50	-2.20	-15.40	-11.40	-17.00	-13.75	0

10. RANKING THE COUNTRIES

Having the results of two multi-criteria approaches, one can rank countries based on each of the weighting systems w1 to w5 in CA, as well as efficiency scores obtained by DEA. This has been done in Table 7, which presents the sustainability rankings of different countries. From the modal sustainability point of view, Denmark is in the best place in both analyses, and Sweden is the country with the worst position in CA and a relatively low position in DEA. It should be noted that the number of countries with the first rank in DEA are relatively high. It is one of the DEA characteristics that DMUs with the best performance in only one dimension have the opportunity of being located in the efficiency frontier.

Table 7. Country ranks based on CA and DEA

Countries	Rank		Countries	Rank		Countries	Rank		Countries	Rank	
	DEA	CA		DEA	CA		DEA	CA		DEA	CA
Austria	1	15	Finland	32	40	Malaysia	21	26	Sri Lanka	1	25
Bangladesh	1	3	France	40	12	Morocco	18	8	Sweden	34	42
Belgium	22	33	Greece	22	18	Netherlands	29	14	Syria	1	11
Brazil	1	6	Hungary	1	7	Norway	33	32	Thailand	25	39
Bulgaria	16	24	India	37	28	Pakistan	28	38	Tunisia	1	2
Burma	1	35	Indonesia	35	21	Peru	1	22	Turkey	19	27
Canada	38	29	Iran	17	20	Philippines	26	37	United Kingdom	41	31
Chile	1	4	Ireland	1	17	Poland	31	19	United States	24	41
Denmark	1	1	Italy	38	34	Portugal	30	30	Venezuela	1	36
Ecuador	1	16	Japan	42	13	Saudi Arabia	20	23			
Egypt	26	9	South Korea	1	5	Spain	36	10			

11. TAXONOMY OF THE COUNTRIES

Based on results of CA, for a comparative sustainability assessment, taxonomy of the countries was developed and is presented in Table 8. It is a systematic classification of peer groups that hints at the relative standing of each nation. Indeed, several classifications were developed using different combinations of the developed elasticities and indices. The taxonomy reported herein was found superior as it reflected all the involved elasticities in a hierarchical order. This shows a systematic and orderly grouping to identify peer countries with respect to the taxonomy criteria. The taxonomy of countries put forward an acceptable ranking for comparative analysis and show casing. The classification can be used in learned lessons and experience sharing among and between groups. In the modeling process, as an example, the information of peer countries may be used as a compliment, or instead of including all countries. Each country is unique due to its multi-faceted backgrounds on social, political, economic, geographical, demographic, environmental, climate and transportation characteristics. The policies for SD should be tailored and customized to a nation's unique circumstance, setting and eminence. Nevertheless, peer comparison would be conducive to policy enhancement.

Table 8. Taxonomy of countries with respect to modal sustainability performances

Category name	The members
Less sustainable	Sweden, United States, Finland, Thailand, Pakistan, Philippines, Venezuela, Burma, Italy, Belgium, Norway, United Kingdom, Portugal, Canada
Middle	India, Turkey, Malaysia, Sri Lanka, Bulgaria, Saudi Arabia, Peru, Indonesia, Iran, Poland, Greece, Ireland, Ecuador
More sustainable	Austria, Netherlands, Japan, France, Syria, Spain, Egypt, Morocco, Hungary, Brazil, Korea, South, Chile, Bangladesh, Tunisia, Denmark

The 42 countries were distributed among 3 groups. The first group, called "less sustainable", includes countries with smaller values (i.e. less than -5) of DCD, (See Table 6 for the values of DCD). The second group, namely "middle", comprises the countries with a DCD score between 5 and -5. The last group, which is called "more sustainable", includes countries with higher values of DCD (>5).

The taxonomy presented a logical framework for comparative analysis and peer group appraisal. It facilitates good practices, learned lessons and experiences information sharing. Nevertheless, the study results were directly influenced by the selected variables. Relevant data on transportation modes, and their direct economic, social and environmental impacts are needed to improve national transportation policies. Comparative assessment could be a compliment to other types of analyses to enhance national policies to support SD.

12. CONCLUSION

The modal transportation sustainability was characterized and studied in an international context. The study database consisted of 39 national variables for 42 countries. The variables were 21 for transportation and 18 for 3 categories of social, economic, and environmental. The selected variables and the period of 1980 to 1995 were suitable in the context of information availability, reliability and completeness. Availability of more relevant comparative national data on transportation modes, and their more direct economic, social and environmental impact could have greatly enhanced the study results. Consequently, the study results would be of more methodological interest, and their direct national policy implications render caution. Nevertheless, the applied comparative assessment methodology could be used as a compliment to any other type of assessment to enhance national policies to support sustainable transportation development. The study also revealed relevant data scarcity when the appraisal of national transportation SD is significantly hampered.

For the selected countries, the database univariate analysis showed significant cross-sectional and time-series variations. The observed trends however were not always in favor of SD. The pair-wise correlation analysis showed that for both 1980 and 1995, on average, a variable 50% of the time significantly correlated with other variables. As a preliminary exploration into modal transportation sustainability, for each country the arc *elasticities* of the social, environmental and economic variables with respect to *modal* transportation variables *were calculated*. Using individual elasticities, the composite sustainability index for transportation modes were suggested. Based on elasticities and composite indices, and using DEA and CA techniques, the SD efficiency scores and benchmarks for each inefficient country in DEA, as well as DCD indices in CA, *were* found. Then, for comparative sustainability assessment, ranking and taxonomy of the countries was developed. The taxonomy resulted in 3 groups. It facilitated comparative appraisal among and between the identified peer groups. The outstanding groups reflected countries with superior values for efficiency scores. They could be used for showcasing, experience and good practice information sharing. The study confirmed the significance of modal transportation balancing and SD challenges, especially for developing countries.

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REFERENCES

1. Ingram, G. K. & Liu, Z. (1997). *Motorization and road provision in countries and cities*. Washington D.C. World Bank.
2. Vaziri, M. & Rassafi, A. A. (2003). Globalization and sustainable development: European experience. *Proceedings of 7th International Conference on Global Business and Economic Development,* Bangkok, Thailand, 36-42.
3. Barter, P. A. (1999). An international comparative perspective on urban transport and urban form in Pacific Asia: The challenge of rapid motorization in dense cities. Ph.D. Thesis, Murdoch University, Pert, Australia.
4. World Commission on Environment and Development (WCED), (1987). *Our common future.* Oxford University Press, Oxford.
5. Gudmundsson, H. & Hojer, M. (1996). Sustainable development principles and their implications for transport. *Ecological Economics*, *1*, 269-282.
6. Organization of Economic Cooperation and Development (OECD), (1996). Towards sustainable transportation. *OECD Proceedings of the Vancouver Conference*, OECD.
7. Vaziri, M. & Rassafi, A. A. (2001). An appraisal of road transport sustainable development in the asian and pacific region. *Technical Papers of International Seminar on Sustainable Development on Road Transport,* New Delhi, India, III39-III46.
8. Charnes, A., Cooper, W. W. & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research, 2*, 429-444.
9. Emrouznejad, A., Ali Emrouznejad's DEA Homepage. http://www.deazone.com, Warwick Business School, Coventry CV4 7AL, UK.
10. Banker, R. D., Charnes, A. & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science, 30*, 1078-1092.
11. Giuliano, G. A. (1985). Multicriteria method for transportation investment planning. *Transportation Research: Part A, 19A*, 29-41.
12. Afgan, N., Carvalho, M. G. & Hovanov, N. Y. (2000). Energy system assessment with sustainability indicators. *Energy Policy*, *28*, 603-612.

13. Alberta Round Table, (Accessed July 2002). *Indicators and Measures of Sustainability*. http://iisd1.iisd.ca/educate/learn/measures.htm.
14. Bossel, H. (1999). *Indicators for sustainable development: theory, method and applications*. International Institute for Sustainable Development, Canada.
15. Hanley, N. (Accessed July 2002). Measuring and modeling indicators of sustainable development. http://www.susx.ac.uk/Units/gec/ph4summ/hanley.htm.
16. Hardi, P. & Zdan, T. (1997). *Measuring sustainable development: review of current practice*. International Institute for Sustainable Development. Occasional Paper 17, Canada.
17. Hart, M. (Accessed July 2002). *Hart environmental data sustainable measures*. http://www.sustainablemeasures.com.
18. Morse, S., McNamara, N., Acholo, M. & Okwoli, B. (2001). Sustainability indicators: the problem of integration. *Sustainable Development*, *9*, 1-15.
19. Murcott, S. (Accessed July 2002). *Appendix A: definitions of sustainable development*. Sustainability Indicators Symposium", http://www.sustainableliving.org/appen-a.htm.
20. Murcott, S. (Accessed July 2002). *Appendix C: criteria of sustainable development*. Sustainability Indicators Symposium", http://www.sustainableliving.org/appen-a.htm.
21. Jalal, K. F. & Rogers, P. P. (2002). Measuring environmental performance in Asia. *Ecological Indicators, 2*, 39-59.
22. Organization of economic cooperation and development (OECD), (2002). *OECD in Figures: Statistics on the Member Countries*, OECD.
23. World Bank. (2002). *The world development indicators 2002 CD-ROM*, World Bank, Washington D.C.
24. United Nations (UN), (2000). *Statistical Yearbook*, 45th Edition. United Nations, New York.
25. Moffatt, I., Hanley, N. & Wilson, M. D. (2001). *Measuring and modeling sustainable development*. Parthenon Publishing Group, London.
26. United Nations (UN), (2000). *Reports on the aggregation of sustainable development*. 9th Session of the Commission on Sustainable Development, Background Paper, Division for Sustainable Development, Department of Economic and Social Affairs, United Nations, New York.