A COMPARATIVE APPRAISAL OF ROADWAY ACCIDENT FOR ASIA-PACIFIC COUNTRIES

Manouchehr Vaziri

Department of Civil Engineering, Sharif University of Technology
P.O. Box 11155-9313, Tehran, Iran
manouchehrvaziri@yahoo.com

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Abstract This paper describes an attempt to shed some light on road safety in Asia Pacific region by characterizing and assessing its road accidents. The relevant national road accident data were extracted from centralized data sources of international agencies. Due to data incompleteness and missing values, 21 Asia Pacific countries, presenting more than half of the world's population, were selected for detailed analysis. The study database consisted of 7 variables, covering years 1980 and 1995. The univariate and multivariate statistical analyses for the selected countries showed interesting results and relations for the selected variables. Accident rates, reflecting road accident risk and intensity, were developed, evaluated and modelled. Deploying multi-criteria analysis techniques such as data envelopment analysis, DEA, provided appropriate bases for cross-sectional appraisal and target setting. As safety is one of the aspects of sustainable transportation, arc elasticity of road accident variables with respect to demographic, economic and road transportation supply variables through time were developed and analysed. Based on the developed elasticities, a composite road safety sustainability index was suggested. The appraisal of road accident for the Asia Pacific countries suggested that road accident has posed a creeping public safety crisis for the region. The study showed that the magnitude of road accident problem varied considerably among countries. The study offers the methodology and conclusions of a comparative macroscopic road accident appraisal for the Asia Pacific region.

Keywords Highway accident, Traffic safety, Accident analysis, Comparative assessment, National appraisal, Asia-Pacific countries, Data envelopment analysis, DEA

چکیده این مقاله ایمنی راه در منطقه آسیا و اقیانوسیه را با استفاده از خصوصیات تصادفات جاده‌یی مشخص و ارزیابی مینماید. اطلاعات ملی مربوطه از بانکها ی اطلاعاتی بین المللی استخراج شده است. کمبود اطلاعات پژوهش را به ۲۱ کشور محدود نمود. اطلاعات ۷ متغیر برای سالهای ۱۹۸۰ و ۱۹۹۵ بانک اطلاعاتی را تشکیل داد. تحلیل‌های آماری تک و چند متغیره نتایج جالبی را نشان داد. نرخ تصادفات ارزیابی و مدل سازی شد. روش چند ضابطه ای پوشش داده‌ها بکار گرفته شد. کشتسانی تصادفات نسبت به متغیرهای جمعیّتی و اقتصادی برای تحلیل توسعه پایدار مورد استفاده قرار گرفت. شاخص ترکیبی از کشتسانیها ساخته شد. ارزیابیهای این پژوهش نشان داد که تصادفات جاده‌ای در منطقه بحرانی است گرچه در کشورها متفاوت می‌باشد. این پژوهش رویکرد و نتایج یک مطالعه کلان و مقایسه ای را برای تصادفات جاده ای ارائه میدهد.

1. INTRODUCTION

Transportation plays a key role in economic and social development. Without access to resources and markets, growth stagnates and poverty perpetuates. Without access to jobs, health, education, recreation and other amenities, quality of life suffers. Nevertheless, transportation has many spillover effects such as congestion, safety, pollution and non-renewable resource depletion. Indeed, throughout the world, countries are increasingly concerned about improved public safety, particularly transportation safety. The concept of sustainable transportation was derived from the general sustainable development term that embraces all sectors of human activity [1].

Sustainable development was popularised in the 1987 report of the World Commission on Environment and Development, the Brundtland Commission. The Commission defined sustainable development as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Subsequently, the definition proposed by the Organization for Economic Co-operation and Development, OECD, contained safety as one of the key elements of a sustainable transportation system [2]. Indeed, road accident is among the important dimensions of transportation sustainable development when studies have suggested that globally nearly one million persons are killed and over twenty million injured in road accidents each year. In 1990, road accidents occupied ninth place in the global table for cause of death. By the year 2020, it is estimated that road accidents will move up to sixth place. Measured in terms of years of life lost and disability-adjusted life years, it is further estimated that they will be in second and third places for the year 2020, respectively. Financially, the adverse impact of road accidents is estimated to lead to global annual economic losses of more than 500 billion US dollars [3, 4, 5]. Road safety development, as a critical global issue, needs much more attention and demands cooperative, comprehensive, coordinated and continuous commitments and actions.

Road safety situation is much worse in developing than developed countries; fatality rates of developing countries are estimated to be 10 to 25 times higher than those of developed countries; and more than three-quarters of road accident casualties occur in developing and transition countries, though they account for less than one third of global motor vehicle ownership. The road accident costs are estimated to consume around 1 to 4 percent of GDP in developing countries [6, 7]. Road safety problems are increasing in most developing countries and effective actions need to be taken if the situation is not to continue deteriorating [3, 4, 8, 9].

More than 4 billion people and 60 percent of the world population reside in the Asia Pacific region. The region is consisted of 70 countries and territories. Over the last two decades, Asia Pacific has been experiencing rapid changes in terms of economic growth, urbanization, and vehicle ownership. These and other factors have resulted in increasing road safety problems with sharp increases in accidents and fatalities. It is estimated that almost half of all global road accident casualties and fatalities occur in the region [4]. For the region road safety is not only an issue with economic dimensions, it is also an issue with social and equity dimensions, affecting every person, especially the disadvantaged and poor.

This paper presents an appraisal of road safety for the Asia Pacific region. The objective of the study was to characterize and evaluate national road accident using comparative cross-sectional and through time analyses. Limited data were available and were extracted from centralized sources of international agencies such as United Nations and Word Bank. Due to data incompleteness and missing values, only 21 countries were selected for detailed analysis. The study database consisted of 7 variables, covering years 1980 and 1995. The comparative analysis shed some light on the road accident variability among the selected countries. The database univariate and multivariate statistical analyses showed interesting results and patterns. The multivariate analyses included correlation analysis, mathematical modelling, elasticity analysis and data envelopment analysis, DEA. Road accident rates were developed, evaluated and modelled. Using accident rates as surrogates of safety performance measures, the DEA was deployed to endogenously construct non-linearly arranged set of best practice countries when the weight of each safety performance measure was endogenously determined based on optimization techniques. To further assess road accident, especially in the context of sustainable development and through time, elasticity of road accident variables with respect to demographic, economic and road transportation supply variables were evaluated. The elasticities were used to develop a composite road safety sustainability index. The paper offers the methodology and conclusions of a comparative macroscopic road accident appraisal for the Asia Pacific region. Figure 1 is a schematic flow diagram of sequential major stages of the study.

The first stage of the study was road accident relevant information gathering and database development for the Asia Pacific countries. The second stage was preliminary analysis of the database. This consisted of univariate statistical analysis, to assess the database variability, and correlation analysis, to explore possible linear relationships among database variables. The third stage was the comparative appraisal of national road accident and safety for the selected countries. The appraisal consisted of cross-sectional and through time analyses. The background and literature review of each stage are explained in its following pertinent sections. Although the study findings are based on a rather limited database, the methodology can be applied to any other time and

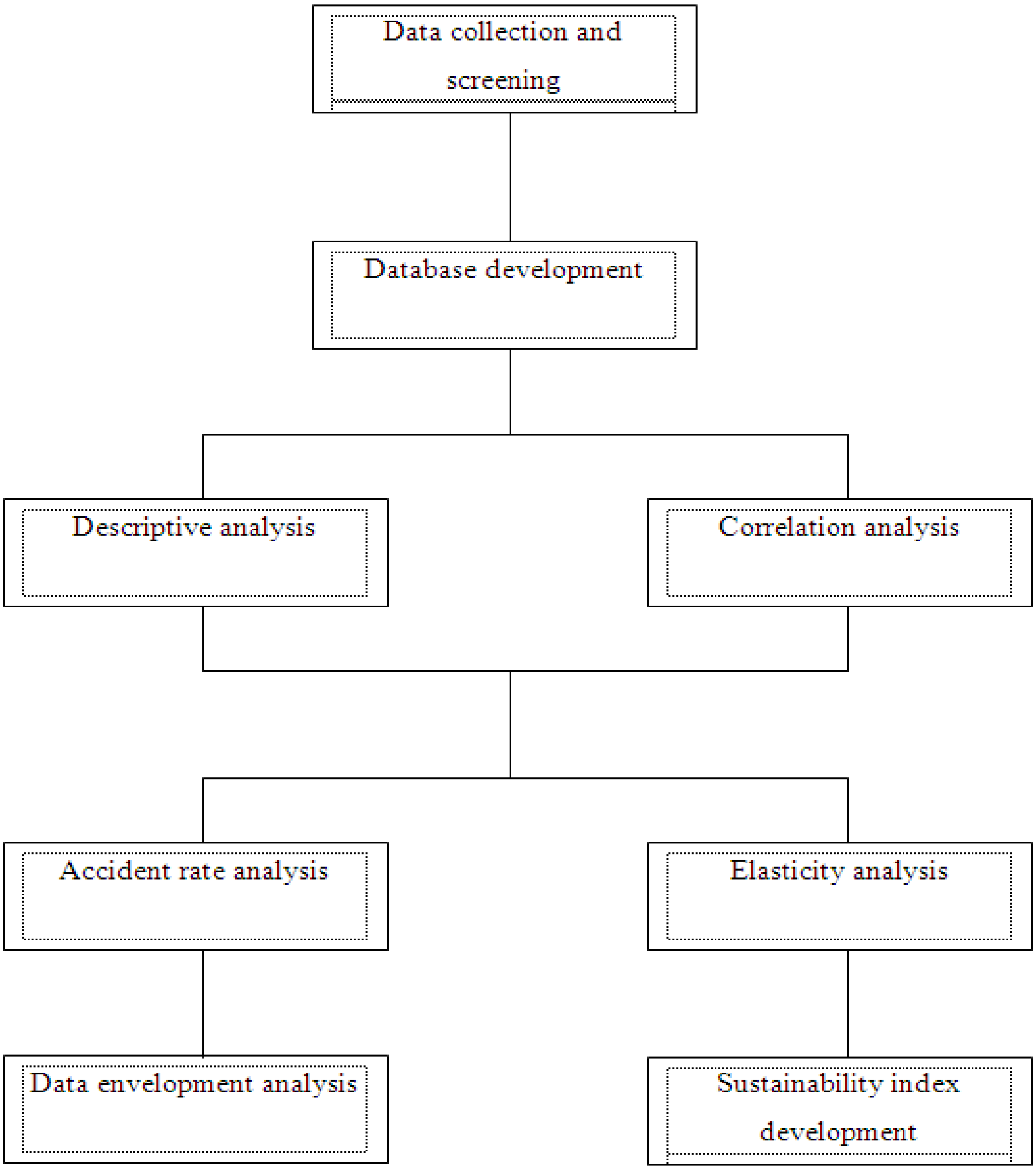

Figure 1. Flow diagram of sequential major stages of study

geographic scope for further elaboration of the road accident issues. The study explored several empirical relations between accident variables and socio-economic variables; nevertheless, assessing causal relationships needs further research and theory building. Indeed, frequently transportation systems, as large and complex human systems, are explained and predicted by empirical models.

2. DATABASE DESCRIPTIVE ANALYSIS

The limited study resources confined the data collection to information gathering from the international databanks [10, 11, 12, 13, 14]. The study important databanks were the Asia Pacific Road Accident Database, APRAD, and the International Road Traffic Accident Database, IRTAD [10, 14]. Initially, by extracting information regarding more than 200 pertinent variables, the study database was developed. The data reliability bore the assumption that for the accessible databases, definitions, under reporting and not reporting of road accidents were similar among countries. These centralized accessible databases on road accident showed many missing values, especially more than 95% for the Asia Pacific developing countries. Efficacious accident database development is among the fundamentals of any road safety development at any pertinent level including national and regional.

The process of data refinement and screening of more than 200 variables of the initial study database included several stages of univariate and multivariate statistical analyses, including descriptive and factor analyses. The criteria for selection of the study time period, variables and countries include: covering significant Asia Pacific countries, limiting missing cases to 5%, covering key accessible and pertinent aggregate characteristics. The final study database consisted of 7 national aggregate variables for 21 countries for the years 1980 and 1995. The study results could have greatly enhanced if more recent data was available. However, more than 75% of the Asia Pacific countries had reported accident data only up to 1995 to accessible centralized databases [10, 12, 14]. Indeed, for the key national road accident database APRAD, the 70 member countries and territories provide their national data to the UNESCAP, and then the information is compiled into the database, accessible through the UNESCAP website [14]. The study could thus only utilize up to the year 1995 data, the most updated information for more than %75 of the Asia Pacific member countries. Even for the study period of 1980-1995, road accident data showed many missing values, especially more than 95% for the Asia Pacific developing countries. The ideal time-series database for this study would have been centralized databases with no missing values that had been updated to study year 2007. Furthermore, data availability of more relevant variables such as national vehicle kilometres could have further enhanced study results. Nevertheless, the selected transportation fleet and infrastructure variables were acceptable surrogates for national vehicle kilometres. The selected countries were among the most populace in the region. The study database variables, being neither unique nor standard and far from ideal, are described in Table 1. From 50 Asian countries and territories, 17 were selected, namely, Bangladesh (BA), Brunei (BR), China (CH), Hong Kong (HK), Japan (JP), India (IN), Indonesia (ID), Iran (IR), South Korea (KS), Malaysia (MA), Pakistan (PA), Philippines (PH), Russia (RU), Singapore (SN), Sri Lanka (SR), Thailand (TH), and Vietnam (VI). From 20 Pacific countries and territories, 4 were selected, namely, Australia (AU), Fiji (FJ), New Zealand (NZ), and Samoa (SM). The selected 21 countries and territories presented more than half of the world's population, or 3.22 billion for 1995.

The univariate statistical analysis of the database shed light on the database cross-sectional and through time variability. The analysis covered computation of statistics such as minimum, maximum, mean, standard deviation and coefficient of variation, as summarized in Table 2. For each variable, the table shows the statistics for 1980 and 1995, and the changes during the 15 years. For example, ACC80 presents the number of road accident in year 1980, and ΔACC presents the change in number of road accidents from 1980 to 1995. The study database showed high variability as reflected by the coefficients of variation in the range 1.41 to 2.97. All the variables, on the average, showed growth. Base on the mean values, number of accidents, injuries and fatalities showed

TABLE 1. Description of the Database Variables

Variable	Category	Description	Dimension
ACC	Road accident	Total annual number of road accidents	Accidents
INJ	Road accident	Total annual number of road accident injured persons	Injured persons
FAT	Road accident	Total annual number of road accident fatalities	Deaths
VEH	Transportation fleet	Total number of motor vehicle in use	1000 vehicles
NET	Transportation infrastructure	Total network length of public roads	1000 kilometres
POP	Demographic	Total population	1000 persons
GDP	Economic	Annual gross domestic product per capita based on 1995 constant US dollars	US dollars

TABLE 2. Descriptive Analysis of the Database Variables

Variable	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation
ACC80	165	476677	59737	104828	1.75
ACC95	161	730012	85829	170135	1.98
ΔACC	-93682	253335	26091	77478	2.97
INJ80	154	599040	62570	130806	2.09
INJ95	120	881951	96286	200602	2.08
ΔINJ	-36368	282911	33715	85836	2.55
FAT80	11	35001	6012	9320	1.55
FAT95	11	68402	11073	19986	1.81
ΔFAT	-2209	46182	5060	13238	2.62
VEH80	4	49244	4559	10786	2.37
VEH95	11	81722	11007	18514	1.68
ΔVEH	2	32478	6448	9193	1.43
NET80	1.2	1190	254	403	1.59
NET95	1.7	2173	359	590	1.64
ΔNET	0.2	983	105	234	2.23
POP80	155	981240	114711	241603	2.11
POP95	165	1204900	146550	306113	2.09
ΔPOP	10	242030	31838	66472	2.09
GDP80	168	29435	5884	8852	1.50
GDP95	277	42186	7940	11211	1.41
ΔGDP	-11870	13890	2057	5412	2.63

44.12, 53.88, and 84.16% increase, respectively, from 1980 to 1995. Furthermore, base on the mean values, during 1980 to 1995, motor vehicles, road network, population and gross domestic product per capita increased 141.43, 41.34, 27.75, and 34.96%, respectively. The two highest growths belonged to number of vehicles and road accident fatalities. These unparallel growths were not aligned with road safety enhancement, and raise concerns about sustainable development of transportation during the study period.

The study database univariate analysis showed significant cross-sectional and through time variability, as was reflected by the coefficients of variation. The through time changes were not in support for road transportation sustainable development in the Asia Pacific region. On the contrary, they suggested that a creeping disaster was evolving in the region's road safety.

3. CORRELATION ANALYSIS

To develop an understanding of the interrelationship among the database variables, as a first step for multivariate analysis, pair-wise correlation analysis for 1980, 1995, and the changes, was performed. The size of the 21×21 correlation matrix prevented their display herein. The matrix revealed a number of interesting patterns and was found useful in subsequent road accident rate, DEA and elasticity analyses. Many pairs of variables were found correlated at a level of significance 0.05. Based on the 21×21 correlation matrix, on the average, a variable was 62.4% significantly and positively correlated with the other variables. This means that out of 441 correlation coefficients, after excluding the 21 auto-correlation coefficients or correlation coefficients of variables with themselves, 262 were significant and positive values. No significantly negative correlation was found among the 21 variables. This means that none of the 441 correlation coefficients was significantly negative. A road accident variable, on the average, was significantly correlated with other road accident variables, transportation variables, and other variables, 74.96, 86.96 and 42.66%, respectively. The road accident variables showed the highest percentage of correlation with number of motor vehicles and road network.

A road accident variable from ACC80, ACC95 and ΔACC, on the average, was correlated with other road accident variables, other transportation variables and other variables, 91.6, 94.4 and 50.0%, respectively. The ACC80 was correlated with ACC95, ΔACC, INJ80, INJ95, ΔINJ, FAT80, FAT95, ΔFAT, VEH80, VEH95, ΔVEH, NET80, NET95, ΔNET, ΔPOP and GDP95. The ACC95 was correlated with ACC80, ΔACC, INJ80, INJ95, ΔINJ, FAT80, VEH80, VEH95, ΔVEH, NET80, NET95, POP80, POP95, GDP95 and ΔGDP. The ΔACC was correlated with ACC80, ACC95, INJ80, INJ95, ΔINJ, FAT80, FAT95, ΔFAT, VEH80, VEH95, ΔVEH, NET80, NET95, ΔNET, POP80, POP95 and ΔPOP.

An injury variable from INJ80, INJ95 and ΔINJ, on the average, was correlated with other road accident variables, transportation variables and other variables, 75.0, 88.8 and 38.8%, respectively. The INJ80 was correlated with ACC80, ACC95, ΔACC, INJ95, ΔINJ, FAT80, FAT95, ΔFAT, VEH80, VEH95, ΔVEH, NET80, NET95, ΔNET, GDP80 and GDP95. The INJ95 was correlated with ACC80, ACC95, ΔACC, INJ80, ΔINJ, VEH80, VEH95, ΔVEH, NET80, NET95, GDP80, GDP95 and ΔGDP. The ΔINJ was correlated with ACC80, ACC95, ΔACC, INJ80, INJ95, VEH80, VEH95, ΔVEH, NET80, NET95, GDP95 and ΔGDP.

A fatality variable from FAT80, FAT95 and ΔFAT, on the average, was correlated with other road accident variables, transportation variables and other variables, 58.3, 77.7 and 50.0%, respectively. The FAT80 was correlated with ACC80, ACC95, ΔACC, INJ80, FAT95, ΔFAT, VEH95, ΔVEH, NET80, NET95, ΔNET, POP80, POP95 and ΔPOP. The FAT95 was correlated with ACC95, ΔACC, FAT80, ΔFAT, VEH95, ΔVEH, NET80, NET95, ΔNET, POP80, POP95 and ΔPOP. The ΔFAT was correlated with ACC95, ΔACC, FAT80, FAT95, ΔVEH, NET80, NET95, ΔNET, POP80, POP95 and ΔPOP.

The correlation analysis reflected significant correlations among 21 variables. Although most of significant statistical correlations could provide interesting clues of relationships between accident variables with other variables, some were difficult to interpret. As a significant conclusion of the study, the lack of any negative correlation in the 21x21 correlation matrix suggested that growths in motor vehicle fleet, road network, population and gross domestic product per capita were concurrent with and could have contributed to road accident burden across Asia Pacific region. Nevertheless, assessing such causal relationships needs further research and theory building.

4. ACCIDENT RATE ANALYSIS

The ratios of accident variables to other variables, such as population or number of vehicles, often are considered as measures reflecting road accident risk and intensity [15]. The ratio form normalizes numerator variable with respective to denominator variable to reflect rates and to facilitate interpretation and analysis. In this study 12 road accident rates were developed. For the rates, the ratio numerators were 3 road accident variables of ACC, INJ and FAT. The ratio denominators were 4 other variables of POP, GDP, VEH and NET. The results of univariate descriptive analysis for year 1980, 1995 and changes from 1980 to 1995 are summarized in Table 3. For example, ACC/POP80 presents the road accidents per 1000 persons in year 1980, and Δ(ACC/POP) presents the change in the road accidents per 1000 persons from 1980 to 1995. As the table shows, the mean values for 1980 and 1995 are evidences of high intensity and risk of road accident for the Asia Pacific region. Decrease in a given rate reflects enhancement in road safety and transportation sustainable

TABLE 3. Descriptive Analysis of Accident Rates

Rates	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation
ACC/POP80	0.03	8.59	1.95	2.08	1.06
ACC/POP95	0.03	14.81	1.96	3.20	1.63
Δ(ACC/POP)	-2.56	6.23	0.01	1.78	127.14
ACC/GDP80	0.06	694.60	81.43	197.07	2.42
ACC/GDP95	0.14	921.05	78.32	210.99	2.69
Δ(ACC/GDP)	-240.21	244.06	-3.10	77.71	-25.06
ACC/VEH80	3.55	161.53	37.43	41.46	1.11
ACC/VEH95	1.52	79.17	14.37	17.05	1.19
Δ(ACC/VEH)	-158.69	-0.75	-23.06	34.50	-1.49
ACC/NET80	33.80	13550.00	1258.10	2901.18	2.31
ACC/NET95	20.98	9058.82	895.24	1930.26	2.16
Δ(ACC/NET)	-4491.18	1483.57	-362.85	1219.29	-3.36
INJ/POP80	0.02	5.13	1.66	1.71	1.03
INJ/POP95	0.02	7.80	1.62	2.15	1.33
Δ(INJ/POP)	-2.96	4.87	-0.04	1.38	-34.4
INJ/GDP80	0.01	482.30	63.10	138.40	2.19
INJ/GDP95	0.02	768.42	61.54	167.09	2.72
Δ(INJ/GDP)	-224.96	286.12	-1.57	82.25	-52.39
INJ/VEH80	4.15	150.06	30.39	33.24	1.09
INJ/VEH95	1.85	52.08	11.88	13.22	1.11
Δ(INJ/VEH)	-112.32	-1.37	-18.50	24.74	-1.34
INJ/NET80	39.52	17121.67	1343.30	3684.86	2.74
INJ/NET95	23.97	12092.94	1081.23	2674.76	2.74
Δ(INJ/NET)	-5028.73	2366.44	-262.06	1323.27	-5.05
FAT/POP80	0.01	0.25	0.10	0.07	0.65
FAT/POP95	0.01	0.29	0.11	0.73	0.69
Δ(FAT/POP)	-0.11	0.19	0.00	0.06	42.31
FAT/GDP80	0.01	129.87	14.31	34.64	2.42
FAT/GDP95	0.01	180.00	16.84	44.02	2.61
Δ(FAT/GDP)	-12.83	71.15	2.53	15.86	6.27
FAT/VEH80	0.18	14.42	3.44	3.48	1.01
FAT/VEH95	0.13	8.53	1.53	2.02	1.32
Δ(FAT/VEH)	-13.03	-0.05	-1.91	2.87	-1.50
FAT/NET80	4.03	335.00	64.24	76.37	1.19
FAT/NET95	2.25	269.79	58.69	68.69	1.17
Δ(FAT/NET)	-117.35	109.33	-5.55	40.32	-7.26

development, whereas, growth reflects undesirable situation. The rates for 1980 and 1995 showed high cross sectional variability as reflected by coefficients of variation in the range of 0.65 to 2.74. The change of rates from 1980 to 1995 showed higher coefficients of variation in the range of –52.39 to 127.14. The larger coefficients were observed for those rates whose mean value did not significantly change, such as for Δ(ACC/POP), Δ(ACC/GDP), Δ(INJ/POP), Δ(INJ/GDP) and Δ(FAT/POP). Among the remaining 7 changes of rates, Δ(FAT/GDP) mean value was positive and undesirable. The key road accident rates related to population, namely, ACC/POP, INJ/POP and FAT/POP, did not change significantly. Their high mean values suggest significant risk and intensity of road accident in the Asia Pacific region. Furthermore, their lack of any significant reduction during 1980 to 1995 is discouraging and alarming. Nevertheless, the situation significantly varied by country or territory.

To develop an understanding of interrelationship between the 12 accident rates and the region's transportation supply and economy, as a first step, pair-wise correlation analysis for 1980 and 1995, was performed. The 3 selected transportation supply and economy rates for correlation analysis were vehicles per capita, VEH/POP, network length per capita, NET/POP, and GDP. The two 12x3 correlation matrices for 1980 and 1995 showed 25.00 and 16.66% significant correlations, respectively. Among significantly correlated pairs, the negative correlations for 1980 and 1995 were 28.57 and 16.66%, respectively. The ACC/POP and INJ/POP were positively correlated with VEH/POP and GDP, for both 1980 and 1995. The FAT/POP was positively correlated with VEH/POP for both 1980 and 1995, and with NET/POP and GDP for 1980. The only significant negative correlations were for FAT/VEH, with VEH/POP for 1980 and 1995, and with GDP for 1980. The results of correlation analysis were also alarming and hinting at road accident problems for the region. The key accident rates of ACC/POP, INJ/POP and FAT/POP, in the cases of significant correlation, showed only positive correlation. Only FAT/VEH, in the cases of significant correlation, showed negative correlation.

Several scatter-grams were drawn to provide clues for simple models explaining accident rates by other variables. The scatter-grams often suggested non-linear relationships, when the statistically significant correlations had already confirmed possibility of developing statistically significant linear models. To develop simple accident rate models, 11 typical mathematical relationships between the 12 accident rates and 3 transportation supply and economy rates were evaluated. They were linear, growth, compound, quadratic, logarithmic, cubic, S shape, exponential, inverse, power and logistic forms. As a result for each of the above-said forms, 36 models, similar to 12×3 pairs in correlation matrix, were developed. The models were single variable with constant. The models' dependent variables were the 12 road accident rates, the independent variables were the 3 selected transportation supply and economy rates. Consequently, for 1980 and 1995, total of 792 models were evaluated. Among the 11 forms, the power form model showed the highest mean value for R squares, significant relations based on F-test and significant coefficients based on t-test. The power model is presented as:

$$Y = a\,(X)^{b} \tag{1}$$

Where Y is the dependent variable, X is the independent variable, a and b are the model's coefficients. Equation 1 confirmed the domination of linear relationships between the logarithms of accident rates with the logarithms of explanatory variables, as was reported before in the literature [15]. Table 4 shows the 21 power models that passed the F-test and t-test at a level of 0.05. The models consisted of 5 ACC rates, 4 INJ rates and 12 FAT rates. The VEH/POP, NET/POP and GDP appeared in 8, 3, 10 models, respectively. For road safety, negative sign for coefficient b was desirable. In other words, accident rates would be desired to decrease with higher transportation supply and economy. As Table 4 shows, this happened in less than forty five percent of the developed models. The coefficient b was negative for 9 out of 21, models related to table row numbers of 4, 8, 10, 11, 13, 16, 17, 20 and 21. These were 8 FAT rate models plus one ACC rate model of row number 13. The coefficient b was positive for 4 FAT rate models, 4 ACC rate models and 4 INJ rate models. For road safety improved

TABLE 4. Selected Power Models for Road Accident Rates

No.	Dependent variable	Independent variable	Coefficient a	Coefficient b	R square
1	ACC/POP80	VEH/POP80	9.130	0.709	0.66
2	INJ/POP80	VEH/POP80	8.975	0.754	0.72
3	FAT/POP80	VEH/POP80	0.296	0.400	0.70
4	FAT/VEH80	VEH/POP80	0.296	-0.600	0.84
5	ACC/POP95	VEH/POP95	5.112	0.769	0.59
6	INJ/POP95	VEH/POP95	4.793	0.802	0.64
7	FAT/POP95	VEH/POP95	0.212	0.394	0.56
8	FAT/VEH95	VEH/POP95	0.212	-0.606	0.75
9	FAT/POP80	NET/POP80	0.641	0.342	0.42
10	FAT/NET80	NET/POP80	0.641	-0.658	0.73
11	FAT/NET95	NET/POP95	0.369	-0.750	0.68
12	ACC/POP80	GDP80	0.003	0.761	0.74
13	ACC/GDP80	GDP80	12482.8	-0.956	0.44
14	INJ/POP80	GDP80	0.002	0.775	0.74
15	FAT/POP80	GDP80	0.006	0.344	0.50
16	FAT/VEH80	GDP80	139.83	-0.562	0.72
17	FAT/GDP80	GDP80	24992.3	-1.373	0.57
18	ACC/POP95	GDP95	0.004	0.677	0.55
19	INJ/POP95	GDP95	0.002	0.762	0.70
20	FAT/VEH95	GDP95	41.84	-0.488	0.59
21	FAT/GDP95	GDP95	41048.6	-1.381	0.50

through time, if the same variables appeared in the models for both 1980 and 1995, it was desirable that the value of b, either positive or negative, decreased from 1980 to 1995. This is evident by computing the point elasticity of Y with respect to X for Equation 1, which would result in a value equal to coefficient b. The models that had similar dependent and independent variables for both 1980 and 1995 were 9 pairs. These were pair models for row numbers (1, 5), (2, 6), (3, 7), (4, 8), (10, 11), (12, 18), (14, 19), (16, 20) and (17, 21) in Table 4. The 5 pairs that showed decrease in the coefficient b were for table row numbers (3, 7), (4, 8), (10, 11), (14, 19) and (17, 21), though small amounts. These were 4 pairs for FAT rates plus one pair for INJ rates of (14, 19). The coefficient b increased for the other 4 model pairs, 2 pairs for ACC rates, one pair for INJ rates and one pair for FAT rates. For these 8 models, the coefficient b growths were significantly large. The 1980-95 changes of the calibrated coefficients suggest that ACC rates and INJ rates have deteriorated. The positive clues were mostly related to FAT rates that seemed to have gained some improvements due to economic developments. This could have been due to post accident improved emergency and medical treatments.

The modelling showed that 12 accident rates were best explained by power form with respect to vehicle per capita, network length and gross domestic product. The assessment of calibrated models again supported the conclusion that road safety in the Asia Pacific region has not improved during the 1980 to 1995, especially for ACC rates and INJ rates.

5. DATA ENVELOPMENT ANALYSIS

Each developed accident rate was a unique dimension addressing a particular aspect of the national road safety. To facilitate single dimensional appraisal, based on the database economic, demographic and transportation variables, different peer groupings could be analyzed and deployed, such as country groupings into 2 groups of rich-industrial and poor- non-industrial. Nevertheless, due to multi dimensionality of accident rates, all countries together were comparatively evaluated by multi criteria analysis. The appraisal of multi dimensional road safety required methods that take into consideration multiple criteria simultaneously. Various quantitative methods have been developed that are different in weighting schemes of involved criteria [16, 17, 18]. Multi criteria analysis often requires two types of information, a set of performance measures characterizing the system of interest and its objectives, and a set of weights reflecting the importance and priorities among performance measures. For simultaneous consideration of the developed accident rates, among various multi criteria techniques, Data Envelopment Analysis, DEA, were found suitable.

The DEA method provided countries with superior road safety situations for years 1980 and 1995. Data Envelopment Analysis, DEA, extends the single output-input ratio efficiency measurement to multi output/input situations. The DEA provides a framework both for formulation and interpretation of compound measures that reflect multiple performance measures. The DEA has been extensively used in multi criteria appraisal when it imposes no prior weighting schemes in order to combine criteria. Its concept is developed around the basic idea that the efficiency of any process can be determined by its ability to transform inputs to desirable outputs. The DEA endogenously constructs non-linearly arranged set of best practice entities when the evaluation weight for performance measures are endogenously determined based on optimisation techniques. The DEA delineates the best practice frontiers and realistic target values [19, 20, 21]. This method has been used to evaluate the efficiency of different entities, known as decision-making units, DMU's, responsible for utilizing inputs to obtain outputs of interest. It is a mathematical programming approach for estimating the relative efficiency of processes that can be characterized by their inputs and outputs. The efficiency score reflects the ratio of weighted sum of outputs to weighted sum of inputs. For a set of "n" DMU's, the relative efficiency for a DMU specified by "p", DMU_p, is calculated by maximizing its efficiency score Z_p, subject to the constraints that no DMU from the set can have relative efficiency score of greater than one. The term "relative efficiency" is used because the efficiency of each DMU is calculated with reference to others. This optimisation problem can be presented by the following fractional programming problem:

$$\text{Max } Z_p = \frac{\Sigma\, u_j\, y_{jp}}{\Sigma\, v_i\, x_{ip}} \qquad (2)$$

$$\text{Subject to: } \frac{\Sigma\, u_j\, y_{jq}}{\Sigma\, v_i\, x_{iq}} \le 1 \qquad \text{for all q's}$$

$$u_j\,,\, v_i \ge 0 \qquad \text{for all j's and i's}$$

Where y_{jq} and x_{iq} are the jth output and the ith input of DMU_q, q = 1,…,n, respectively. The u_j and v_i are the weights for the jth output and the ith input of DMU_p, respectively. The above optimisation problem can be converted to a linear programming problem, LP, and easily solved. Thus, by solving "n" pertinent LP's of the "n" DMU's, their efficiency scores can be determined [19].

The DEA can be used to estimate efficiency scores or efficient levels of inputs or outputs from either an input or output orientation or from an orientation that allows both input and output levels to simultaneously change. The input orientation provides estimates of the amount by which inputs could be proportionally reduced and still produce a given output level. The output orientation provides estimates of the amount by which outputs could be proportionally expanded given existing input levels. Since countries can improve their safety performances more easily by increasing output safety measures than reducing input transportation activity measures, the output oriented DEA was deployed. Assuming countries as DMU's, after evaluation of several DEA forms, 2 inputs and 3 outputs output-oriented linear programming DEA with constant return to scale, CRS, and variable return to scale, VRS, were finally selected and deployed [22]. The CRS model presents both technical and scale efficiencies where as VRS model only reflects technical efficiency. The rating and efficiency score that are provided via VRS model will always be higher than the one provided by CRS model except when a DUM is rated efficient by both models. To focus more on technical efficiency and to avoid scale influence, the VRS would be of more relevance for showcasing best practice countries regarding road safety of Asia Pacific region.

The DEA pertinent input-output information was extracted and determined from the study database. The inputs were gross domestic product per capita, GDP, and vehicle per capita, VEH/POP. The output safety measures were the inverses of accident rates related to vehicle variable, namely VEH/ACC, VEH/INJ and VEH/FAT. The results

TABLE 5. Results of DEA for 1980

DMU	CRS		VRS	
	Efficiency	Bench Marks	Efficiency	Bench Marks
CH	1.00	15	1.00	1
HK	0.13	CH,BA	0.65	PH,PA,JP
KS	0.07	CH,BA	0.23	PH,BA,PA
BR	0.07	CH,BA	0.91	TH,AU,JP
ID	0.66	CH,PA	0.88	PH.PA
MA	0.38	CH	1.00	0
PH	0.64	CH,BA	1.00	6
SN	0.17	CH,BA	0.64	PH,PA,JP
TH	0.36	CH,BA,PA	1.00	1
VI	0.66	BA,PA	1.00	0
BA	1.00	8	1.00	1
IN	0.87	CH	0.93	CH,PH, PA
IR	0.43	CH,PA	1.00	1
PA	1.00	5	1.00	6
SR	0.63	CH	0.81	PH,PA
RU	0.17	CH,PA	0.88	IR,AU
AU	0.14	CH	1.00	2
JP	0.25	CH,BA	1.00	3
NZ	0.20	CH	1.00	0

TABLE 6. Results of DEA for 1995

DMU	CRS		VRS	
	Efficiency	Bench Marks	Efficiency	Bench Marks
CH	0.72	BA,PA	0.81	BA,PA
HK	0.25	BA	0.52	ID,PH,JP
KS	0.12	PH,BA,PA	0.54	ID,AU
BR	0.10	PH,BA,PA	0.80	ID,AU
ID	0.96	BA,PA	1.00	8
MA	0.19	PH,VI	0.76	ID,PH,AU
PH	1.00	12	1.00	9
SN	0.21	PH,BA	0.71	ID,PH,JP
TH	0.15	PH,VI,PA	0.52	ID,PH,AU
VI	1.00	6	1.00	2
BA	1.00	9	1.00	2
IN	0.91	PH,VI,PA	0.60	PH,VI,BA
IR	0.39	PH,VI,PA	0.62	ID,PH,AU
PA	1.00	10	1.00	2
SR	0.39	PH,VI	0.42	PH,VI,PA
RU	0.18	PH,VI,PA	0.47	ID,PH,AU
AU	0.17	PH,BA,PA	1.00	7
JP	0.18	PH,BA	1.00	2
NZ	0.11	PH,BA,PA	0.69	PH,AU

of DEA are shown in Tables 5 and 6. Due to missing information, Fiji and Samoa were excluded from the analysis. The DEA provided overall scores for each country reflecting the overall road safety efficiency for 1980 and 1995. The derived scores were dependent to the deployed accident rates and other pertinent socio-economic variables. They were neither unique nor universal or standard. Nevertheless, they provided clues to overall pictures of national road accident risk and safety situations relevant to comparative cross sectional assessment. The practices and experiences of bench mark countries with low accident risk and high safety scores can be used as valuable clues for safety enhancement by other countries after due consideration of local factors. The national road safety enhancement schemes, often successfully experienced by economically advanced countries such as Sweden, Norway and Denmark, include allocation of extensive financial and manpower resources, enhancement of infrastructures and vehicles, expansion of driver and public education, enforcement of traffic rules and regulations, enhancement of insurance policies and medical facilities. Deployment of these schemes can further foster road safety.

6. ELASTICITY ANALYSIS

To further characterize road accident changes during the period 1980 to 1995, elasticity of each road accident variable with respects to other variables, namely, other road accident, transportation supply, population and gross domestic product per capita variables was evaluated. The arc elasticity E of a variable Y with respect to a variable X for the period t1-t2 reflects the percent variable Y changes with respect to one percent change of the variable X as is shown by Equation 3 [23]:

$$E_{Y/X,t1\text{-}t2} = \frac{(Y_{t2} - Y_{t1})/(Y_{t2} + Y_{t1})}{(X_{t2} - X_{t1})/(X_{t2} + X_{t1})} \quad (3)$$

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. When the difference between t1 to t2 gets very small, the arc elasticity converges to point elasticity. For the period of 1980 to 1995, eighteen arc elasticities were computed. The results of descriptive analysis for the developed elasticities are summarized in Table 7. As the table shows,

TABLE 7. Descriptive Analysis of Road Accident Elasticities

Elasticity	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation
$E_{ACC/INJ}$	-93.04	35.69	-2.05	21.81	10.64
$E_{ACC/FAT}$	-13.49	172.80	12.14	38.35	3.16
$E_{ACC/VEH}$	-13.51	0.89	-0.50	2.97	-5.94
$E_{ACC/NET}$	-18.31	16.91	0.83	6.26	7.54
$E_{ACC/POP}$	-7.73	5.87	0.74	3.10	4.19
$E_{ACC/GDP}$	-3.71	10.03	0.69	3.01	4.36
$E_{INJ/ACC}$	-1.41	10.11	1.38	2.64	1.91
$E_{INJ/FAT}$	-27.27	64.39	4.68	16.88	3.61
$E_{INJ/VEH}$	-5.04	0.80	-0.19	1.22	-6.42
$E_{INJ/NET}$	-6.82	15.39	0.13	4.10	31.53
$E_{INJ/POP}$	-3.97	6.26	0.61	2.70	4.43
$E_{INJ/GDP}$	-1.50	3.71	0.59	1.40	2.37
$E_{FAT/ACC}$	-1.19	9.50	1.19	2.45	2.06
$E_{FAT/INJ}$	-141.98	40.89	-3.88	32.01	-8.25
$E_{FAT/VEH}$	-1.18	0.93	0.16	0.46	2.87
$E_{FAT/NET}$	-7.43	10.54	0.90	3.53	3.92
$E_{FAT/POP}$	-2.31	5.11	1.09	1.95	1.79
$E_{FAT/GDP}$	-1.81	5.48	0.73	1.40	1.92

based on coefficients of variation, there were large variations in the elasticities. The mean value for elasticities showed desirable sign 27.77%, namely for $E_{ACC/FAT}$, $E_{ACC/VEH}$, $E_{INJ/FAT}$, $E_{INJ/VEH}$ and $E_{FAT/INJ}$. Table 2, shows that the mean value of all variables increased during 1980 to 1995, consequently, the desirable situation would be negative mean value for elasticities, except for $E_{ACC/INJ}$, $E_{ACC/FAT}$ and $E_{INJ/FAT}$. The mean values for elasticities were positive except for $E_{ACC/INJ}$, $E_{ACC/VEH}$, $E_{INJ/VEH}$ and $E_{FAT/INJ}$. For unfavourable signs, situation was worse if the absolute value of elasticity exceeded one. This was observed for 4 elasticities, namely, $E_{ACC/INJ}$, $E_{INJ/ACC}$, $E_{FAT/ACC}$ and $E_{FAT/POP}$. The elasticity analysis for the period 1980 to 1995 suggested further concerns for unfavourable road accident trends. In the context of road safety, sustainable transportation development had been hampered by road accident.

For comparative assessment of road safety sustainability, elasticities of road accident variables with respect to other variables were used to develop a composite road safety sustainability index. There are many suggestions to combine different sustainability variables to develop a single measure to present the approximate overall status [24, 25, 26, 27]. To aggregate elasticities and make them comparable, first Z scores were computed by:

$$ZE_{Y/X} = \frac{E_{Y/X} - M(E_{Y/X})}{SD(E_{Y/X})} \quad (4)$$

Where $ZE_{Y/X}$ is the Z score of the $E_{Y/X}$ as computed by Equation 3, M and SD are functions that provide the mean and the standard deviation of their arguments. The Y is a road accident variable, ACC, INJ or FAT. The X is a variable from other variable group, VEH, NET, POP or GDP. The composite index CI using the Z scores was:

$$CI = \frac{\Sigma\,\Sigma\,(SE_{Y/X}\,WE_{Y/X}\,ZE_{Y/X})}{\Sigma\,\Sigma\,|SE_{Y/X}\,WE_{Y/X}|} \quad (5)$$

Where CI is the composite index for comparative assessment, $SE_{Y/X}$'s are coefficients that are +1 for elasticities with desirable positive sign and -1 for those with desirable negative sign, $WE_{Y/X}$'s are the weighting factors for elasticities, and $|SE_{Y/X}WE_{Y/X}|$ is the absolute value of $SE_{Y/X}WE_{Y/X}$. Table 8 shows the results of the above-mentioned computations, using equal weighting factors, $WE_{Y/X} = 1$ for all Y's and X's. As the CI's computed by Equations 4 and 5 have the mean value of zero, the negative values for CI's should be interpreted in the context of comparative assessment and ranking. As the table shows, some countries showed high CI value like Australia.

The results of comparative cross-sectional and through time appraisals were not always similar. A country could have shown a cross-sectional superior standing at a given point in time, where as considering through time trends and changes different comparative conclusions could be reached. For example, based on variable return to

TABLE 8. Road Safety Composite Index for the Selected Countries and Territories

Country	Composite index	Country	Composite index
Australia, AU	1.21	New Zealand, NZ	0.32
Bangladesh, BA	-0.37	Pakistan, PA	0.08
Brunei, BR	0.03	Philippines, PH	0.26
China, CH	-0.45	Russia, RU	0.28
Fiji, FJ	-0.04	Samoa, SM	0.29
Hong Kong, HK	0.38	Singapore, SN	0.58
India, IN	-0.51	South Korea, KS	0.01
Indonesia, ID	0.66	Sri Lanka, SR	-0.34
Iran, IR	-0.32	Thailand, TH	-0.71
Japan, JP	-1.11	Vietnam, VI	-0.36
Malaysia, MA	0.11	Country average	0.0

scale DEA results of Tables 5 and 6, Japan was found as a bench mark for Hong Kong in years 1980 and 1995. This is contrary to road safety composite index evaluation for the 15 year period of 1980-95 of Table 8, while Japan showed an inferior value as compared with Hong Kong. To facilitate cross-sectional and through time appraisals, for the selected countries and territories, the results of variable return to scale DEA and elasticity composite road safety index analysis are summarized in the bar chart of Figure 2. For the DEA, the country's efficiency scores, DEA80 and DEA95 with the range of zero to one, were extracted from Tables 5 and 6. For elasticity analysis, the country's composite index CI of Table 8, with the range of -1.11 to 1.21, was rescaled as NCI-80-95 with the range of zero to one. Fiji and Samoa were excluded from DEA due to missing data.

It should be emphasized that the elasticity values reflect the extent to which the two associating variables are changing consistently through time. It is an indicator that shows the harmony or disharmony between the safety variables and the other ones through time. It doesn't refer to the magnitude of the variables. Rather, it indicates their relative trends. Road safety practices and policies of countries with high CI's can be learned from, customized and adapted by others for improvement in public safety and transportation sustainable development. National road safety programs must be comprehensive, continuous, cooperative and coordinated to facilitate sustainable road safety development. They should address major relevant sectors and provides systematic and consistent vertical and horizontal integration of all related activities.

7. CONCLUSIONS

The study offers the methodology and conclusions of a comparative macroscopic road accident appraisal for the Asia Pacific region. The paper describes an attempt to shed some light on road safety by characterizing and assessing national road accidents. The accessible databanks were

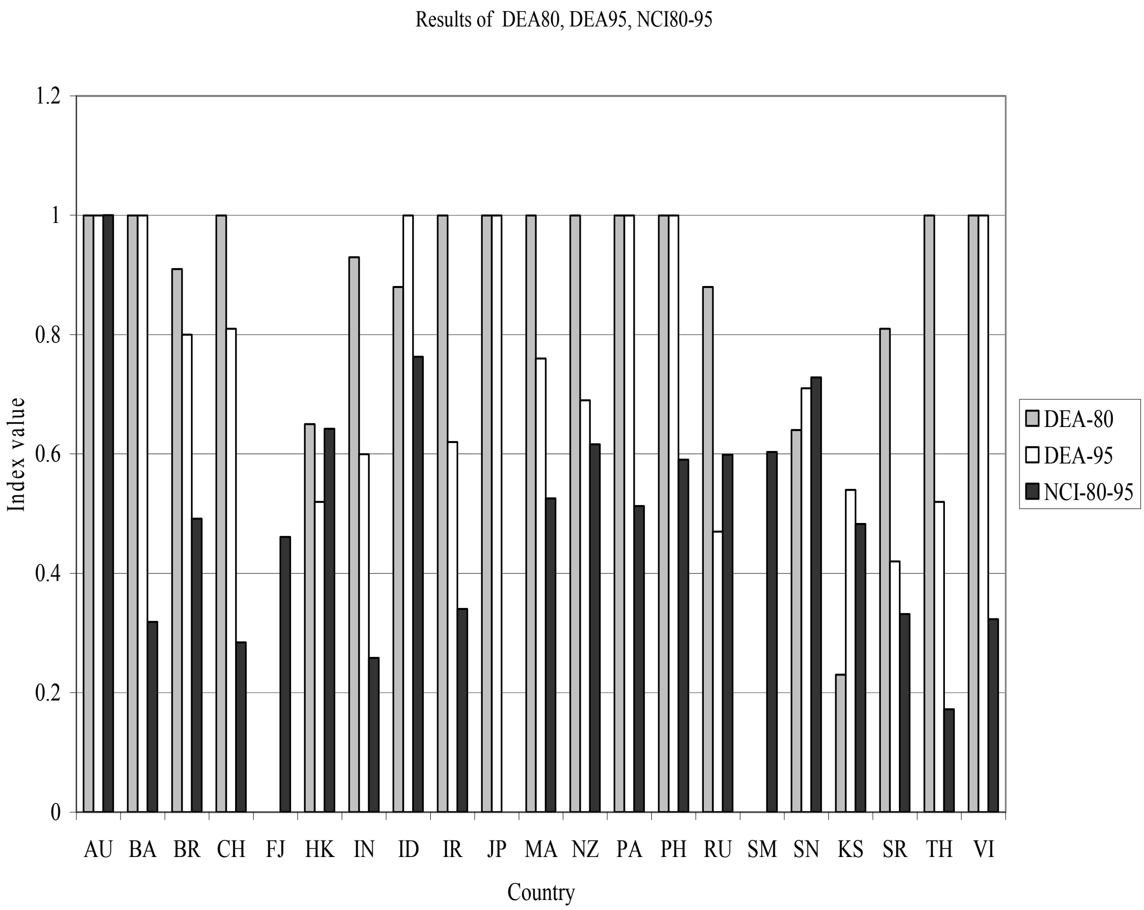

Figure 2. Results of DEA and elasticity analysis

overwhelmed by road accident data incompleteness and missing values. Twenty-one countries and territories, presenting more than half of the world's population, were selected for detailed analysis. The study database consisted of 7 national statistics, covering years 1980 and 1995. They were annual road accidents, annual injuries, annual fatalities, motor vehicles, road network length, population and gross domestic product per capita.

The univariate and multivariate statistical analyses for the selected countries showed interesting results and relations for the selected variables. The study database univariate analysis showed significant cross-sectional and through time variability. The mean values for road accident variables for 1980 and 1995 were high, and their growths during the 15 years were not in support of road transportation sustainable development in the Asia Pacific region. The multivariate analyses included correlation analysis, mathematical modelling, elasticity analysis and data envelopment analysis, DEA. The correlation analysis showed statistically significant relationships between road accident variables and other variables. The road accidents, injuries and fatalities increased as population, vehicle fleet, road network length and gross domestic product per capita increased. Utilization of effective national road safety planning could have prevented or reversed these trends. Accident rates, reflecting road accident risk and intensity, were developed, evaluated and modelled. The power model was found as the best form explaining accident rates as functions of vehicle per capita, road network length per capita and gross domestic product per capita. In other words, linear relationships were found between the logarithms of accident rates with the logarithms of vehicle ownership, per capita road network length and gross domestic product. The models evaluation suggested that a creeping disaster had evolved in the region's public safety by road accident. Indeed, the 1980-95 changes of the models' coefficients reaffirmed road accident and injury rates deterioration, even with due consideration of their models' independent variables. For comparative cross sectional assessment and target setting, the multi criteria method of DEA was found suitable and deployed. The DEA results portrayed countries with superior road safety for years 1980 and 1995. The elasticity analysis shed further light on the road accident variables changes and trends during the period of 15 years. The observed road accident elasticities reflected many unfavourable accident trends, hinting further on a regional safety crisis in the making. As safety is one of aspects of sustainable transportation, elasticity of road accident variables with respect to demographic, economic and road transport supply variables were used to develop a composite road safety sustainability index. For the selected countries, the index was computed and was further suggested for comparative assessment and ranking. As expected, the results of comparative appraisal of cross-sectional and through time analyses not always were found to be similar. A country could have shown a cross-sectional superior standing at a given point in time, where as considering through time trends and changes different comparative conclusions could be reached.

In this study, development of relevant accident rates and elasticities, and deployment of DEA facilitated comparative cross sectional and through time appraisal of national road safety for the Asia Pacific region. During 1980-95, road accident lingered a significant threat to human life and property, increasingly affecting Asia Pacific nations. The study did not indicate promising history of road accident for the selected countries and hinted at critical road safety challenges for the 21st century with possible evolvement to a regional disaster. It suggested that road accidents in the Asia Pacific region were impeding transportation sustainable development and were destroying lives and livelihoods. Deployment of proactive road safety policies and programs should prevent such crises to take place. Although the study findings are based on a rather limited database, the methodology can be applied to any other period or region for addressing pertinent road accident issues.

Further cross-sectional and through time road safety research with similar and/or updated data at different geographical scope can be undertaken. As many of the suggested conclusions are empirical and based on limited observations, sound theoretical and causality relationships should be explored, developed, tested and further evaluated. Key to further research is availability of efficacious accident database. Indeed proper accident database development is among the fundamentals of any road safety development at any pertinent level including national and regional.

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