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STRATEGIES TO REDUCE TRAFFIC ACCIDENT RATES IN DEVELOPING COUNTRIES: LESSONS LEARNED FOR ASSESSMENT AND MANAGEMENT

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ABSTRACT

Strategy formulation and approaches in assessment and management of traffic engineering challenges related to the impact of traffic accidents on road networks in developing countries is problematic. The core focus of this paper consists of research output derived from traffic accident data available in South Africa. The availability of traffic accident data will be assessed to formulate applicable intervention traffic management strategies. Furthermore, the paper will include a statistical analysis and projection of such road traffic accident data in order to derive at certain tendencies from existing realities.

From the outcome of the research lessons learned for improved traffic planning, management and formulation of intervention strategies in developing countries will be deduced. Improved traffic and transportation planning practices is a priority in developing countries and economies and will guide resilient and sustainable traffic planning in developing countries.

Keywords: traffic accident, traffic management, traffic planning, transportation planning

1 INTRODUCTION

Patel *et al*. [1] report that road traffic injuries (RTIs) are the eighth-leading cause of death worldwide. The Department of Transport agency in South Africa that is responsible for road safety, road traffic law enforcement and data collection and management on traffic accidents and mortality is the Road Traffic Management Corporation (RTMC) [2] (Section 22 of the RTMC Act and Treasury Regulation 28.2). Traffic data from Ref. [2] reveal that some 24 fatalities/100,000 population occur in 2015 in South Africa.

Notwithstanding the fact that Australia's per population road death rates have declined 57.9% for the period 1975–1995 they are continuously working on their road safety. Langford & Newstead [3] report that Australia adopts a Safe System Strategy in 2003 that is similar to the one that have been implemented in Sweden and the Netherlands to support safer roads, safer speeds and safer vehicles. The outflow of this was only 5.6 fatalities per 100,000 population in 2010. In 2011, they also released a new National Road Safety Strategy which includes an update of key statistical measures. Hence, to improve road safety in developing countries, there must be on-going planning and management. This paper will guide developing countries in improving road safety by lessons learned from assessment of road safety data and in showing how to manage, analysis and predict traffic accidents which must inform intervention strategy formulation and management.

2 GAPS AND PROBLEMS WITH SOUTH AFRICA'S ROAD SAFETY DATA

Table 1 shows a summarised assessment of the RTMC website data by classifying the data into four classes i.e., major crashes, fatalities, vehicle and licence information. This assessment provides more information on the data available on the RTMC website, the period the data cover and on the format of the available data.

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Table 1: Assessment of the data as available on the RTMC website.

	Data available on the Road Traffic Management Corporation website:	Excel data available for the following period	Data available in annual report format (Not very research friendly)
Vehicle Info.	Year-end Vehicle Population	1920 -2009;	Yes
	Estimated Million Vehicle Kilometres (MVK) travelled	1950-2008;	
	Number of Motorised Vehicles Registered at the end of each Year (per type)	1990-2009;	Yes
	Number of registered vehicles (per province) (per type)	Dec 1999 - Dec 2008;	Yes
	Estimated Million (MVK) Vehicle Kilometres Travelled (per Type of Vehicle) (per Year)	1990-2008;	
	Estimated Average Distance Travelled (per Vehicle) (per Type) (per Year)	1990-2008;	
	Number of Registered Vehicles per Type per Province - End of Year (and per month)	Dec 1999 - Dec 2009;	Yes
	Estimated Fuel Sales for Road Use per Province (per month) - mega litres	2000 - 2009;	
	Estimated Million Vehicle Kilometres Travelled(per Vehicle Type) (per Province)	2000 - 2008; 2007 - Aug 2009;	
	Estimated Million Vehicle Kilometres Travelled (per Vehicle Type) (per Month)	2007 - Aug 2009;	
	Estimated Average Distance Travelled (per Vehicle) (per Type of Vehicle) - kilometres	Jan 2000 - Aug 2009.	
	Number of vehicles de-registered per province (per type)		Yes
Fatalities	No. of Fatalities per Type of Vehicle per 10,000 Registered per province	2001	Yes
	No. of Fatalities per Type of Vehicle per 100 million vehicle kilometres travelled	2001	
	Percentage of Fatalities per Age group (per Road User Group)		Yes
	Percentage contribution of fatalities per age for drivers		Yes
	Percentage contribution of Fatalities per Race		Yes
	Number and Percentage contribution of Fatalities per Gender		Yes
	Fatalities contribution per road users and per province		Yes
	Monthly Number of Fatalities		Yes
	Number of Fatalities per Province over 12 Month Period		Yes
	Fatalities per 100,000 Human Population		Yes
Licences	Number of Learners Licences Issued per Province (per month)	2004 -2009	
	Number of Driving Licences Issued per Province (per month)	2004 -2009	
	Number of Professional Driving Permits (PrDP's) Issued per Province (per month)	2004 -2009	
	Number of vehicles that are Un-Roadworthy, Un-licenced or both (per province) (per type)		Yes
Major crashes	Major crashes per province (per month) (per vehicle types)		Yes
	Annual major crash casualties & fatalities per province	2009 -2015	Yes
	Monthly major crash comparison		Yes
	No. of Vehicles per Type Involved in Fatal Crashes per 10,000 Registered per province	2001	Yes
	No. of Vehicles per Type Involved in Fatal Crashes per 100 million vehicle kilometres travelled	2001	
	Number of Vehicles per Type Involved in Fatal Crashes (per province)	2001 -2008	Yes
	Severity rate of Fatal Crashes per day of week and per province		Yes
	Number of Fatal Crashes per Province per day of week over 3 Month Period (per Province over 12 Month Period)		Yes
	Monthly Number of Fatal Crashes		Yes
	Estimating cost of crashes in South Africa		2004 & 2015

Source: Own construction

The assessment of the available traffic accident data in South Africa concludes that:

- Traffic reports are not released on time on the RTMC website;
- The available data are not reported in a research-friendly format (consider Table 1). Most of the available data must be retrieved indirectly from various Pdf-formatted reports on the website. The restricted data on the RTMC website that is available in EXCEL format are not provided on an on-going basis for analysis. The data must be available in summarised time series format for the most recent time frames of 10 years.
- The data on the RTMC website only report on national and provincial level even though one of the objectives of the RTMC is to establish a partnership between national, provincial and local spheres of government.
- Due to the fact that death certificates do not report the cause of death correctly (e.g., a road accident), it follows that Stats SA annual report on mortality and causes of death under estimate such reported figures.

- Research undertaken by Chokotho *et al*. [4] report extensive data quality problems in the police data, including significant underreporting of traffic injury deaths. In addition, recording of the 'time variables' in the mortuary dataset was substandard. It was further concluded that not all assumptions underlying the use of the capture-recapture method were met; hence, estimates provided by this capture-recapture analysis should be interpreted with caution.
- Annual reports of most municipalities do ot include any data on major crashes, fatalities or vehicle and licence information in the municipality area.

3 AN ANALYSIS OF THE TRAFFIC DATA IN SOUTH AFRICA

3.1 Traffic accident trends

Figure 1 represents a very high linear relationship (correlation coeffisient of 0.975) as would be expected between the number of fatal crashes and the fatalities (per 100 milllion vehicle kilometres travelled). From Fig. 2 follows a recently minimum ratio of 22 for the number of fatalities per 100,000 human population which were measured in 1998 and 2013. Moreover, global maximum ratios of 38 were measured in 1971 and 1972 with local maximum ratios of 36 in 1982, 37 in 1990 and 32 in 2006. Figure 2 clearly indicate that 1974 was a watershed year since prior to 1974 the number of fatalities per 10,000 motorised vehicles was higher than the number of fatalities per 100,000 human population but after 1974 the inverse is true due to motorisation, affordability of vehicles and population growth.

3.2 Statistical analysis of the traffic accident data

The traffic data is time-dependant, therefore an Auto Regressive Integrated Moving Average (ARIMA) model is used to capture the dynamics of the fatalities per human population. For more information on ARIMA models consider Gujurati & Porter [5]. ARIMA models

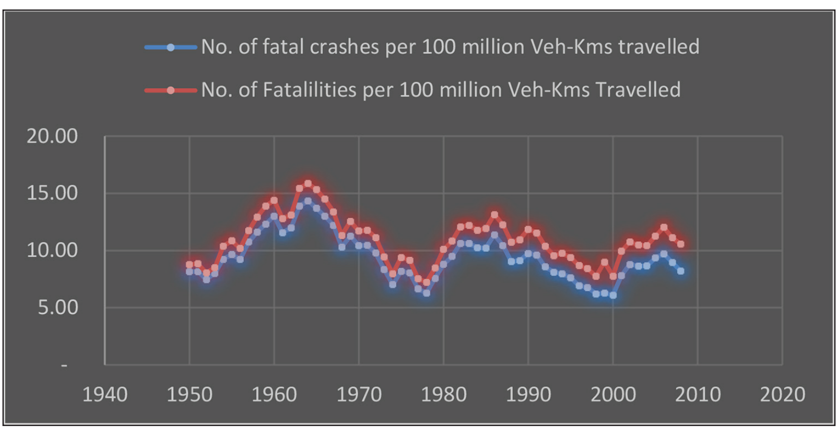

Figure 1: The relationship between the fatalities and fatal crashes (Source: Own construction using data from the RTMC website).

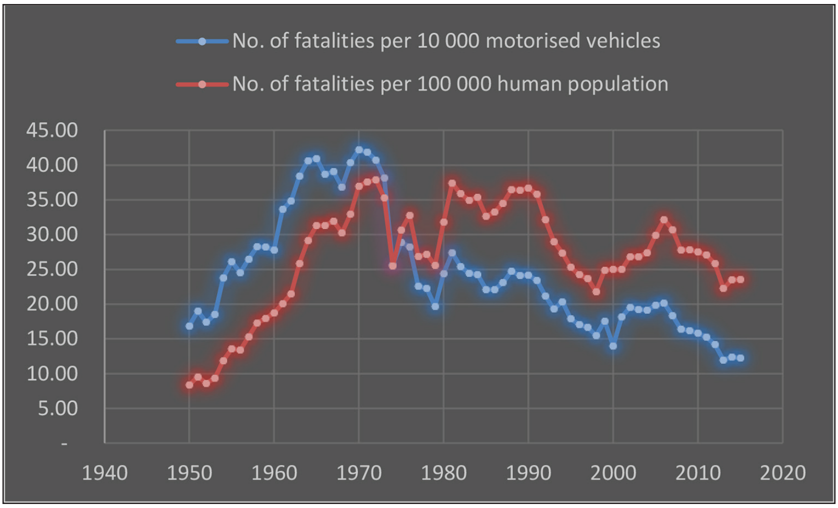

Figure 2: The relationship between fatalities per human population and fatalities per number of motorised vehicles (Source: Own construction using data from the RTMC website).

attempt to capture empirically relevant features (patterns) of the observed data using only information contained in the variable past values and error terms. The Box-Jenkins approach is used to select the appropriate parsimonious ARIMA model. The ARIMA model that estimate the fatality data the best is the ARIMA(1,1,0) model.

The Hodrick-Prescott (HP) filter is a univariate two-sided linear filtering technique which decomposes a time series into a long-term trend and cyclical part. This technique was first used by Hodrick and Prescott to analyse post-war U.S. business cycles in Ref. [6]. In Fig. 3,

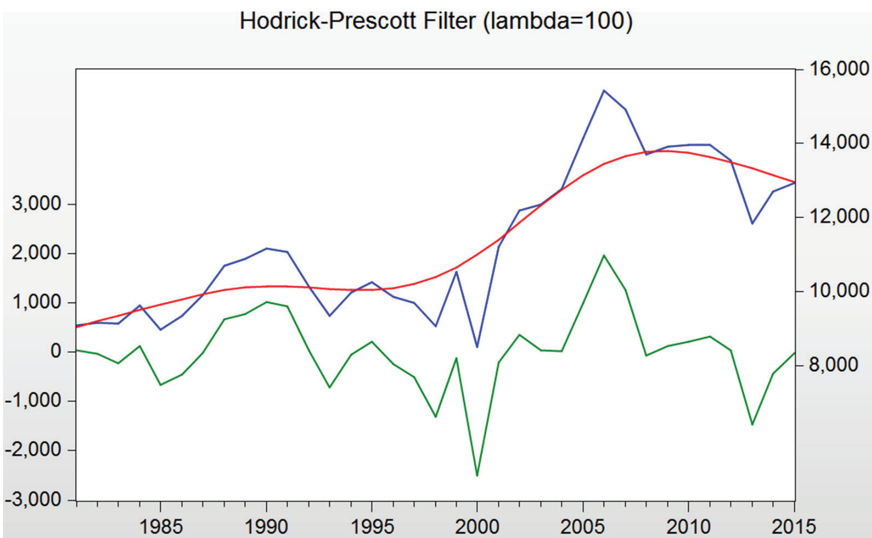

Figure 3: Hodrick–Prescott filter (Source: Own construction using the RTMC fatality data).

Table 2: Models that capture the dynamics of the number of fatalities.

Year	Fatalities	Average Forecast	Exponential Smoothing	Exponential (Holt-Winters - no seasonal)	ARIMA(1,1,0) without constant	Hodrick-Prescott (HP) filter	Moving Average Forecast
1992	10 142			10 142	10 142	9 385	
1993	9 351	10 142	10 142	10 348	9 351	9 492	
1994	9 981	9 747	9 995	9 806	9 981	9 608	
1995	10 256	9 825	9 992	10 143	10 256	9 736	9 825
1996	9 848	9 933	10 041	10 433	9 848	9 889	9 863
1997	9 691	9 916	10 005	10 200	9 691	10 080	10 028
1998	9 068	9 878	9 947	10 024	9 068	10 325	9 932
1999	10 523	9 762	9 783	9 513	10 523	10 634	9 536
2000	8 494	9 858	9 921	10 476	8 494	11 005	9 761
2001	11 201	9 706	9 656	9 195	11 201	11 436	9 362
2002	12 198	9 856	9 943	10 905	12 198	11 898	10 073
2003	12 353	10 068	10 362	12 080	12 353	12 361	10 631
2004	12 772	10 259	10 733	12 490	12 772	12 799	11 917
2005	14 135	10 452	11 112	12 907	14 135	13 182	12 441
2006	15 419	10 715	11 674	14 034	15 419	13 485	13 087
2007	14 920	11 029	12 371	15 278	14 920	13 688	14 109
2008	13 707	11 272	12 845	15 215	13 707	13 792	14 825
2009	13 923	11 415	13 005	14 290	13 923	13 812	14 682
2010	13 967	11 555	13 176	14 220	13 967	13 760	14 183
2011	13 954	11 682	13 323	14 236	13 954	13 649	13 866
2012	13 528	11 795	13 440	14 230	13 528	13 496	13 948
2013	11 844	11 878	13 457	13 909	13 671	13 318	13 816
2014	12 703	11 876	13 157	14 115	13 622	13 137	13 109
2015	12 944	11 912	13 072	14 320	13 639	12 955	12 692

Source: Own construction using fatality data from the RTMC website

the blue line represents the total number of fatalities, the red line shows the long-term trend and the green line indicates the cyclical part included in the fatality data.

In the Single Exponential Smoothing method ŷ_(t + 1) = *α**y_t + (1 – *α*)*ŷ_t, the smoothing series ŷ_t of the actual series y_t is determined as a weighted average of the past values of y_t and the smoothing parameter *α* is calculated by minimizing the sum of squared errors. The Exponential Smoothing (Holt-Winters – No seasonal) method is a double smoothing method; consider Hyndman *et al*. [7] for more on Exponential Smoothing methods.

Other methods like the Past Values Average and Moving Averages were also used in Table 2 to capture the dynamics of the traffic data.

4 PREDICTION OF TRAFFIC ACCIDENTS

In this section, the best forecasting model will be determined by dividing the data up into a training set and a validation set. The training set is used to determine the different parameters (values) of each model in Section 3.2, and the validation set is used to determine the forecast ability of each of these models. Therefore, the values for the forecast accuracy measures given in Table 3 is the result of using the input data (number of fatalities for the period 1992–2015) with training period 1992–2012 and forecast evaluation period 2013–2015. Here, the best forecast model is illustrated to be the Average of all the Past Values which minimum values for the forecast errors e.g., root mean squared error (RMSE), mean squared error (MSE) and the mean absolute percentage error (MAPE). The Average Past Values predict 13,455 road fatalities for 2016 in South Africa.

Further, using the training period (1992–2013) and forecast period (2014–2015) on the road mortality data, the forecast results follows in Table 4. By considering these forecast

Table 3: Forecast evaluation for the number of fatalities.

Forecast Error (2013 -2015)	Ave All Past Forecast	Exponential Smoothing	Exponential (Holt-Winters - no seasonal) Eviews	ARIMA(1,1,0) without constant	Hodrick-Prescott (HP) filter	Forecast Moving Average Forecast
RMSE:	763.69	970.11	1 648.42	1 247.00	1 023.67	1 171.66
MAE (MAD):	630.81	731.63	1 617.71	1 146.94	819.92	876.78
MAPE:	4.92	6.06	13.06	9.34	6.76	7.27

Source: Own construction using the data in Table 2

Table 4: Forecast evaluation for the road mortality rate.

Forecast Error (2014 -2015)	Ave All Past Forecast	Expoential Smoothing	Exponential (Holt-Winters - no seasonal)	Hodrick-Prescott (HP) filter	Forecast Moving Average Forecast
RMSE:	2.65	2.26	0.81	0.49	0.92
MAE (MAD):	2.16	1.84	0.63	0.30	0.62
MAPE:	9.20	7.81	2.66	1.26	2.66

Source: Own construction using data from the models that capture the dynamics of the mortality rate.

errors, we can conclude the best model to predict the mortality rate is the Hodrick–Prescott filter, which predict a road mortality rate of 24 for 2016.

William *et al*. [8] report that a Monte Carlo Simulation is a probability simulation used by decision makers for risk management thus to plan ahead for the future by estimating the relative likelihood and range of the possible uncertain (random) variable values. Hereby the decision makers can assess the likelihood of a desirable outcomes and the risk of undesirable outcomes.

Figure 4 is constructed using South Africa's fatalities per 100,000 human population ratio for the period 2002 to 2015. From using these historical data combined with a Monte Carlo simulation, it follows that the likelihood of having a fatalities per 100,000 human population ratio in the interval (25; 27] is the highest at 28% and the profitability of having this ratio higher than 25 is equal to 71%. Hence, the Monte Carlo method implies that the probability is very high in 2016 for the realisation of a mortality rate greater than 24.

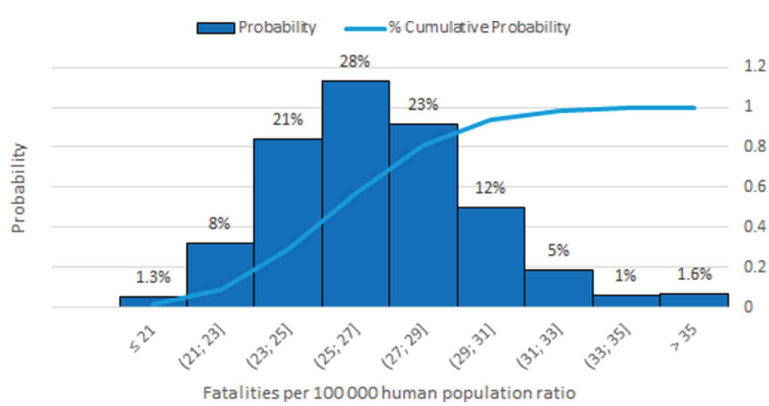

Figure 4: The likelihood of the fatalities per 100,000 human population ratio ordered by different classes (Source: Own construction using the RTMC fatality data).

5 HOW TO ACHIEVE AND SET TARGETS

Tolon-Becerraa *et al*. [9] propose a way of meeting the required European Union road safety target on the reduction of fatalities in a certain period of time. This is done by distributing the effort between the different European Union member countries, using an inverse logarithmic function that penalise in a smooth way countries according to their base year mortality rate. Hence, countries with high base year fatality rates are assigned high rates of reduction in comparison with countries with low base year fatality rates.

This methodology if applied to the provinces in South Africa as illustrated in Fig. 5, using 2011 as base year to meet the UN's target in [10] of halving the 2011 number of fatalities by 2020. Note that the RTMC supports the UN's target in their annual reports.

Due to the fact that the current tendencies and results are due to yesterday's habits, it follows that targets will only be achieved if it is possible to reduce the target by refining and defining the responsibility of the target. Therefore, the best way to meet a target is by diversifying the responsibility to different applicable responsibility levels and by refining the responsibility as much as possible. Hence, the above target methodology combined with progress monitoring must be implemented not only on provincial level but also on local municipality level and must be adapted and monitored on an annual basis. Due to the lack of municipality level road accidents data (and the impossible process of getting hold of it), it is only applied to provincial level in this paper.

6 ROAD ACCIDENT CAUSES TO BE CONSIDERED IN ROAD SAFETY STRATEGIES

6.1 Developed countries

Hughes *et al*. [11] provide the following traffic accidents contributing components and factors that must be managed and coordinated by a Safety Management System:

1. Human (driver/pedestrian/passenger)
   - Compliance to traffic rules (overtaking, speeding, etc.)
   - Impairment (drugs, alcohol, etc.)
   - Abilities and capabilities (license, vision, etc.)

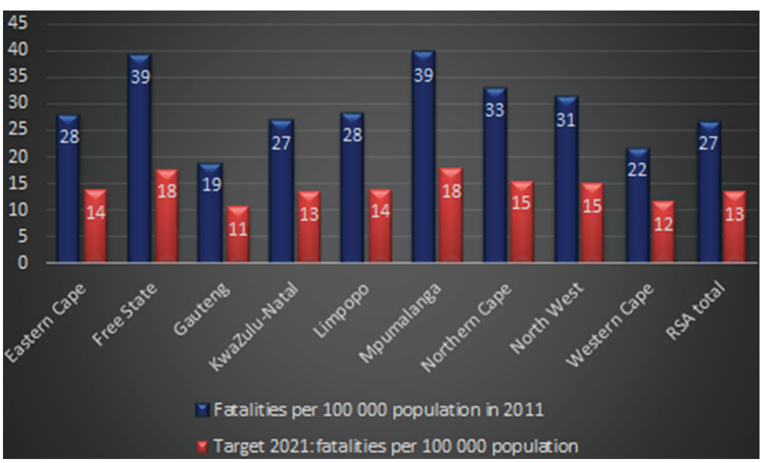

Figure 5: Setting fatality and mortality targets for each province (Source: Own construction using Stats SA population data and RTMC fatality data).

- Attitude and attention (emotion, phone distraction, etc.)
- Helmets and protection clothing utilisation
- Seatbelt utilisation.

2. Vehicle(s)
   - Maintenance, inspections, damage
   - Condition of wheels and tires
   - Condition of brakes
   - Condition of steering, pedals, levers, lights and suspension
   - Design standards
   - Overloading.
3. Road infrastructure
   - Surface (friction, shoulders, potholes, etc.)
   - Geometry (gradient, lanes, no shoulder, curves, etc.)
   - Poor maintenance
   - Traffic volumes
   - Inadequate signs, reflectors, signal, lighting, etc.
   - Obstacles (intersection type, crosswalk, island, etc.)
   - Poor road system (entry and exist of vehicles).
4. Transport and land use
   - Transport alternatives, other modes
   - Spatial arrangement, co-location
   - Accessibility - remoteness, location, service levels
   - Transport integration.
5. Environmental
   - Weather (fog, rain, etc.)
   - Smoke
   - Wildlife
   - Dawn, dusk, night and sun.
6. Socio-economic circumstance
   - Economics (finance, funding)
   - Employment structure
   - Population growth
   - Politics and government
   - Social norms and background
   - Travel purposes and activities
   - Legal (regulation, liability, insurance).
7. Crash response system
   - Emergency services and rehabilitation.

6.2 Developing countries

According to the work done by the World Health Organisation (cf. [12–15]), Nantulya and Reich [16] and Juillard *et al*. [17] the main reasons for the high road traffic fatality and injury rates in Africa are due to one or more of the following considerations:

- Road infrastructure [with the main emphasis on the lack of pedestrian subways and side-walks (pedestrians) cycling infrastructure lanes and the uncorrelated growth between road infrastructure improvement and the number of commuters];

- Human: disregard of cyclists and pedestrians by drivers (inclusive of non-motorised traffic);
- Road infrastructure: lack of road signs;
- Transport and land use: the traffic modal mix on the roads;
- Safety management system: ineffective planning by government inclusive of health, emergency and transport agencies due to poor sampling techniques, varying traffic fatality definitions used by different reporting agencies, underreporting, reporting errors and lack of integration between reporting agencies;
- Socio-economic circumstance and transport and land use: non-existing unavailability or non-affordable public transport;
- Socio-economic circumstance: increase in the utilisation of motorised transport due to economic development, affordability and availability.

Traffic Offence Survey [18] reports the five highest contributory factors in 2015 to fatal crashes in South Africa are due to:

- Human: Jay-walking pedestrians (41.6%);
- Human: Speed too high for circumstances (9.2%);
- Human: Hit and run (8.8%);
- Vehicle: Tyre burst prior to accident (4.7%);
- Human: Intoxicated driver with liquor/drug usage (4.3%).

These five factors contribute 69% to all fatal accidents in South Africa.

From the above, it follows that main components on which developing countries must focus on in their road safety strategies is the human, vehicle, road infrastructure, socio-economic, safety management system and transport and land use.

7 STRATEGIES TO REDUCE TRAFFIC ACCIDENTS

Studying the reduction of road mortalities in the Netherlands (1972), UK (1983) and Spain (1991) Lassarre [19] and Elvik [20] in combination with the papers of Hughes *et al*. [11], World Health Organisation (cf. [12–15]), Nantulya and Reich [16], Juillard *et al*. [17] and Traffic Offence Survey [18] it follows that road safety can be improved if the strategies, function, objectives and output strive on a continuous basis to improve:

Safe Management:

- Risk management: (identification, assessment, analysis, prediction)
- Information (data and research): Use common (police, hospital, mortuary, Department of Transport, Stats SA) accident database. Allowing for more detailed and reliable analyses of data. On municipality level, the location of crash incidents must be used to determine hotspots and to create a hotspot map of crashes in the municipal areas and thereby identifying priority spatial locations for strategy formulation
- Standards and well-defined targets. (Consider Section 5 on ways to achieve targets). Each municipality needs to prioritise and apply sound traffic safety measures in line with the applicable legislative framework with given targets that are based on their appropriate base year performance in order to ensure and boost the countries but also the municipality's road safety and economic statistics
- Capability (skills, knowledge, experience)
- Capacity (financial, human, system, technology)

- Systems (processes, structures, procedures, standards)
- Integration (vertical coordination on national, provincial and local spheres and horizontal alignment of sources on road accident data all using the same database and definitions)
- Implementation and improvement of policy, planning, design, installation, maintenance, monitoring, evaluation, revision.

Safer road infrastructure:

- Improved design of roads and related supporting infrastructures
- Identify pedestrian hazardous locations
- Identification of hazard location (traffic accident hotspots)
- Information on the reason for accident.

Safer vehicles:

- Strong political commitment on design standards
- Enforcement of legislation
- Inspections.

Human component behaviour change:

- Education: Educate young people or road safety using a guide like the Road Safety Cities in Europe, Handbook [21]
- Information (campaigns) on crashes to better the understanding of the risk
- Strong enforcement initiatives with the focus on
    - speed control
    - alcohol consumption *('drink and drive initiatives'*)
    - promotion of helmet utilisation
    - promotion of seatbelt utilisation
    - road user sensitivities related to both motorised and non-motorised modes of transport.

Transport and land use

- Sustainable transport systems like bus rapid transit, to decrease traffic accidents and traffic congestion.

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