Predicting the development of traffic fatalities in Latin-American and Caribbean countries

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Summary

Long-term developments in traffic growth and fatality rate can be rather well described by non-linear functions of time. The basics are an S-shaped function for saturating traffic growth (measured by annual motor vehicle kilometres or motorised vehicle volumes) and an exponentially decreasing function for fatality rate. Each function may be simultaneously modulated by cyclic or auto-regressive functions for deviations from these basic functions. By definition the product of traffic growth and corresponding fatality rate determines the road fatalities. Therefore, reducing road fatalities only can be observed if the fatality rate proportionally decreases more than the traffic grows.

The general validity of the mathematical analysis for traffic growth and fatality risk development are first illustrated by the remarkable fit for the data analyses of long time-series on kilometrage, fatality rate and fatalities in the USA. The analyses for the USA and many other highly motorised countries have shown that the slope of the exponential decreasing fatality rate generally is dependent on the slope of the S-shaped trend in traffic growth. This relation between the underlying main trends of growth and risk as well as the dependence between their deviation patterns from the main trends are theoretically understood as evolutionary growth and delayed risk adaptation of technological systems under deterring and accelerating socio-economic influences. This interpretation as a socio-economic technological evolution of road transport and its evolutionary risk adaptation implies inherently interdependent developments as in biological evolutions where growth also implies adaptation.

Also for Latin-American and Caribbean countries the growth of motorised traffic is made possible by socio-economic changes, while the cyclic modulations of S-shaped traffic growth may express economic upsurges and depressions with delayed effects on risk adaptation. Quantitative data analyses are only shown for Brazil and Chile, because for other Latin-American and Caribbean countries no consistent long time-series of fatalities are available. If traffic growth is not accompanied by a more than compensating risk reduction the result is disastrous for road safety, as is shown by the analyses and prognoses of Brazil and Chile as well as by the estimation for the total 35 Latin-American and Caribbean countries.

In order to prevent a worsening safety outcome of traffic growth, such as the tentatively predicted annual 120 thousand road fatalities in the total of the 35 Latin-American and Caribbean countries around the year 2015, the investments in road safety must be given an as high priority as the investments for traffic growth. If the also briefly summarised road safety policies are not established, the total of road fatalities will amount to nearly two million between 1995 and 2015 in the 35 Latin-American and Caribbean countries. By the most effective road safety policies a total of one million lives and the waste of about 400 billion US-dollar macro-economic costs could be saved. It justifies road safety investments of 20 billion US-dollar per year in the total of the Latin-American and Caribbean countries over the next 20 years.

Contents

1. Introduction

The developments of road safety and traffic over long periods of time in many countries recently have been analysed and successfully modelled on the basis of models for time-dependent macro-system growth and risk adaptation by Oppe and Koornstra (Oppe, Koornstra & Roszbach, 1988; Oppe & Koornstra, 1990; Oppe, 1991a; Oppe 1991b; Koornstra, 1992a). Highly motorised countries show that the percentage of growth in vehicle kilometres is relatively large and nearly constant in the starting phase of the motorisation process, but also show that this percentage diminishes in the later motorisation phases. Since the growth of kilometrage can not be infinite it must be assumed that the total kilometrage eventually has to reach a saturating level. These assertions leads to an underlying S-shaped curve for the growth of road traffic. The so-called (asymmetric) logistic or so-called Gompertz function are such S-shaped curves which fit the long term time-series of annually driven motor vehicle kilometres (or annually registered motor vehicles) for many highly motorised countries rather well in a macroscopic sense. Although the macroscopic developments in motor-vehicle kilometres are mainly described by a saturating S-shaped curve, economic developments may temporary deter and accelerate the growth of traffic. Analysis of data from several countries has shown that the deviations from S-shaped macro-trend curves can be modelled by cyclic patterns around the macroscopic S-shaped curve for traffic growth.

Growth of motorisation is accompanied with serious adverse outcomes for road safety. In the USA and the countries of North West Europe the number of annual road fatalities has increased to a maximum somewhere around the early seventies and levelled off thereafter. The explanation of the rise and fall in fatalities has troubled researchers for a long time, asking what has been the causes for the turn in these developments. The reason for a mainly single peaked development of fatalities, however, can be understood if one realises that the smoothed fatality rate tend to decrease annually by a more or less constant percentage. On the one hand this implies an underlying exponential decay function for the fatality rate development as the model for the main trend in the fatality rate for a country, although there also are cyclic deviations from exponential decay to observe. As a consequence on the other hand somewhere in time there is a turning point where the underlying constant proportional reduction of the exponential fatality rate becomes larger than the eventual diminishing proportional increase of the underlying S-shaped traffic growth. Before that point in time the main trend in fatalities will be increasing and thereafter decreasing, because the product of the macroscopic S-shaped trend curve of the vehicle kilometres and exponential decay curve of the fatality rate gives by definition a single peaked main underlying trend of fatalities. Therefore, nothing else than these two monotonic developments in traffic growth and fatality rate is needed for an explanation of a single peaked underlying main trend in fatalities that has been observed for the macroscopic development of road fatalities in many highly motorised countries (Oppe, 1991a). However, cyclic deviation patterns around the S-shaped trend of growth as well as around the exponential decay of the fatality rate may cause irregularities around that underlying single peaked development of the road fatalities. Sometimes it may cause several smaller local peaks besides the main single peaked trend. As shown in the sequel such local peaks are to be observed for the USA, but the same model analysis of the data for Japan (see: Koornstra, 1993) yields only two marked peaks which mask the underlying single peaked main trend, due to the location and large influence of the longest deviation cycles for Japan.

1.1. Analysis example: USA

In *Figure 1* we show as an example of the S-shaped traffic growth and its cyclic deviations (apart from a lowering shift during World War II) the analysis result for the traffic growth development in the USA. For the USA we have the annual motor vehicle kilometres from 1923 to 1994. Its 72 years constitute the longest time-series for any country available. The traffic growth in the USA determines a so-called Gompertz curve with a saturation maximum of 9445 billion motor vehicle kilometres as the best fitting S-shaped curve. The present mileage is just above 40% of that future maximum, although the motorisation in the USA is already less than two inhabitants per passenger car. Clearly the predicted maximum growth also includes a further population growth and immigration in the USA. Around the underlying S-shaped main trend, there is a significant main cycle with a period of just less than 20 years. Besides this cycle and despite the apparent downward shift in the deviation pattern due to World War II, significant harmonic deviation cycles of almost twice and half that period are present too.

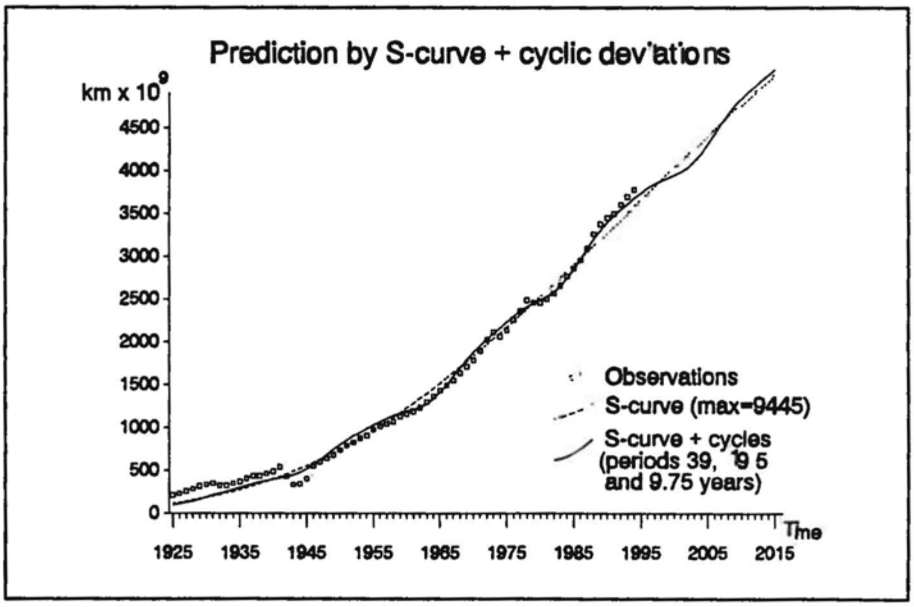

Figure 1. *Kilometre growth in the USA (Gompertz curve with cycles).*

As an illustration of the typical macro-trend in the fatality rates we also analysed the annual fatality rates in the USA for the time-series from 1923 to 1994. In *Figure 2* the observed rates and the fitted exponential decay function with a simultaneously fitted pattern of harmonic cycles for deviations around the exponential decay curve are shown. For the USA the underlying exponential risk decay has an average reduction of about 3.1% per year. Compared to West European countries it is a rather low annual risk reduction percentage. However, due the very long and rather undisturbed history of motorisation the present fatality rate in the USA has become one of the lowest in the world. Also there are apparent cyclic deviations from exponential risk decay, which even describe periods of fatality rate increases. These deviations can be fitted by significant harmonic cycles of 35, 17.5 and 8.75 years periods with diminishing weights.

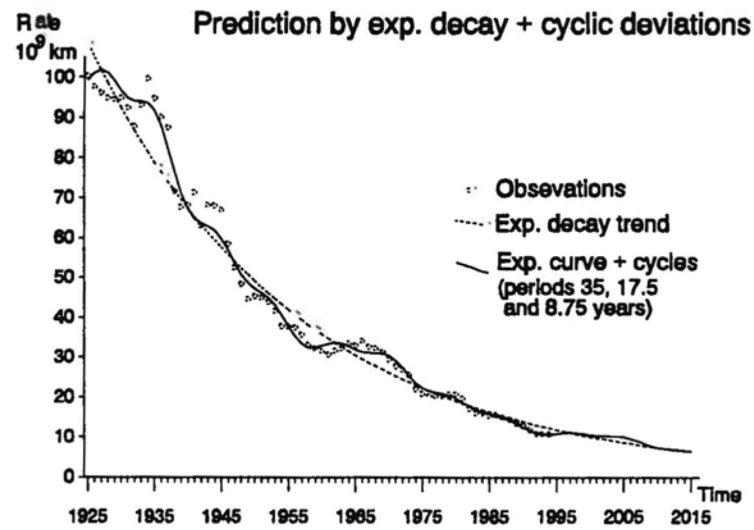

Figure 2. *Fatality rate in the USA (exponential decay curve with cycles).*

Apart from the fitted deviations cycles around the main trend curves, it is evident that there is an underlying exponentially decreasing trend in the fatality rates as well as an underlying S-shaped trend in traffic growth. These underlying curves of a different, but related nature describe the macroscopic trends in traffic growth (for the USA and for many other countries optimally fitted by a so-called Gompertz S-curve) and fatality rate (exponential risk decay) quite well. The product of these underlying curves describes by definition the macroscopic development of the road fatalities, which necessarily is single peaked. That rather hidden peak for the underlying trend in fatalities for the USA lies around 1970.

In *Figure 3* we display the observed annual road fatalities in the USA from 1925 to 1994 as well as its prediction by the product of the fitted and cyclic modulated curves from *Figure 1* and *2*. The cyclic modulation pattern of the deviations from S-shaped growth and exponential risk predict several smaller local peaks corresponding to the observed peaks. The amplitude for the local peaks is higher than for the shortest underlying cycles in growth or risk. These local ups and downs are due to periods of relative higher traffic growth which partially overlap with periods of stagnated decay in fatality rate (local ups) and which are followed by partial period overlaps of relatively less traffic growth and increased reduction of fatality rates (local downs).

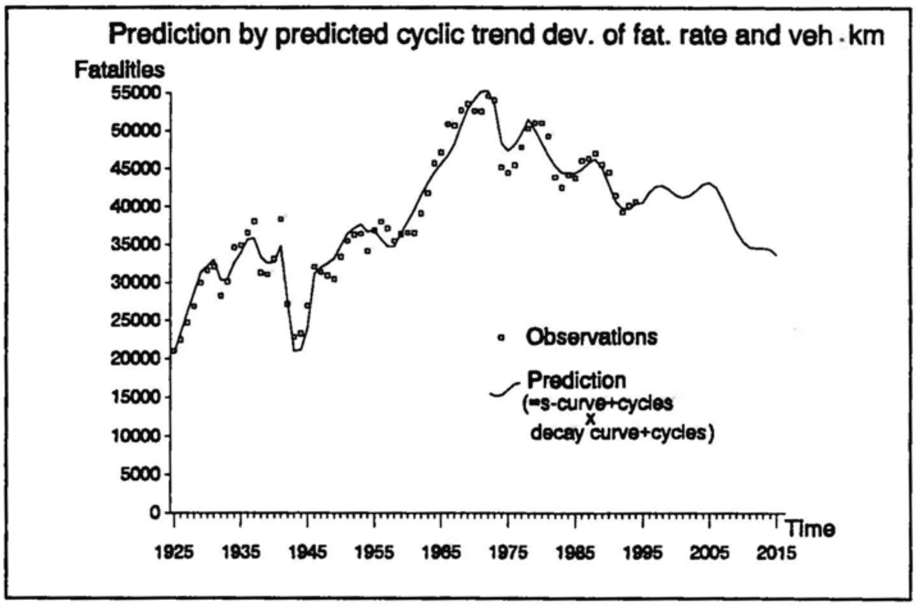

Figure 3. *Fatalities in the USA (product of graphs from Figures 1 and 2).*

It seems as if periods of accelerated growth causes a delayed accelerated decay in fatality rate, while periods of reduced growth causes later partially overlapping periods of stagnated fatality rate decay or even fatality rate increases.

1.2. Theoretical background

The model analyses for many highly motorised countries have revealed that the development of fatalities is largely dependent on the past history of motorisation growth in a country. Countries with a relative long and more or less uninterrupted history of motorisation, like the USA and Great-Britain, nowadays show the lowest fatality rates. The analyses of many other countries have also shown that the fatality rate decreases the steeper the higher the slope of the traffic growth is (Oppe, 1991a; Oppe 1991b; Koornstra, 1992a). In fact Oppe (1991a) has shown that slope parameter of exponential fatality rate tend to have a value which is dependent on the value of the slope parameter for S-shaped traffic growth. Moreover, if this dependency holds between S-shaped growth (Gompertz or specific non-symmetric logistic functions) and exponential fatality rate decay then the level of fatalities is dependent on the derivative of traffic growth and not on its absolute level. Mathematically this follows from these S-shaped functions of time, since its derivative divided by level is an exponential function of time (Koornstra 1988; Oppe & Koornstra, 1990). Its linear relation with time in the exponential fatality rate implies that speed of traffic growth is time-lagged related to decay speed of the fatality rate. Theoretically this is understood as an evolutionary growth of the transport system with a delayed inherent risk adaptation (Koornstra, 1992a).

With growing economic possibilities people will buy more cars and travel more by car, while companies increasingly deliver their goods by vans and trucks. Individuals will use cars not only for business and home-work trips, but also for social and tourist trips and more so the more the economic situation improves and leisure time increases, due to a higher utility for this mode of transport. A growth process that is comparable to growth and selection by survival value in biological evolutions.

The growing road transport asks for an enlarged, improved and maintained road infrastructure. A renewed and enlarged road infrastructure will be established by the pressure of the voting people and lobbies in growing economies of democratic countries. Authorities have to provide that infrastructure in order to fulfil the needs of their inhabitants on the one hand and on the other hand to ensure economic growth. The systems of market economy, transport and democracy constitute a self-organising macro-system (Jantsch, 1980), wherein feedback hypercycles between the subsystems pull and push the road transport evolution (Koornstra, 1992a). Under the condition that resources are available this macro-system evolution leads to a more or less autonomous growth of road transport.

Any evolutionary growth consists of multiple replacements of subsystems by better adapted subsystems. Renewal and enlargement of the road infrastructure are multiple replacements by in the average better and safer roads for already existing parts of the road infrastructure. Also there are multiple replacements of transport means by new cars and of drivers by more younger drivers, which enhance safety by more safer cars and delayed increases of average driver experience. Also the multiple replacement of traffic laws and their enforcement lead to more road safety. In this way the replacement of subsystems by in the average more then one better adapted subsystem in the transport system constitute an inherent risk adaptation in the technological transport evolution. The decreasing fatality rate, therefore, is understood as an evolutionary adaptation process, wherein risk adaptation and road transport growth are dependent as are growth and adaptation in biological evolutions.

Generally the increased safety by risk adaptation will be delayed with respect to the growth of road traffic, due to the time needed for planning and design, for decision taking on several levels, for the (re)construction of infrastructure, for the implementation of safety measures as well as for the increase in driver experience. This dependence of risk adaptation with respect to growth causes a lagged relation between the slopes of trends in traffic growth and fatality rate as well as lagged correlations between periodic deviations from trends in traffic growth and fatality rate.

1.3. Prediction by cross- and autoregression

The cyclic deviations around S-shaped growth suppose that we also can predict the development of traffic growth by auto-regression functions. The cyclic deviations from exponential decay of the fatality rate as well as the lagged correlations between deviations from S-shaped growth and from exponential risk decay also means that the fatality rate can be predicted by an auto-regression and lagged cross-regression between deviations from S-shaped growth and from exponential risk decay. It seems likely that such an approach even will give more accurate predictions, since it assumes no exactly cyclic deviation patterns and may also take into account recent deviations in the developments for a more accurate prediction of the near future. In order to show the validity of the predictions by this regression approach, we use the data from the USA up to 1968 and predict the already known (but not used) next 26 years up to 1994. This retrospective prediction, as well as the prognostic prediction after 1994 using data from before 1995, are shown in *Figures 4, 5* and *6.*

For traffic growth the auto-regression prediction is based on the lagged slope deviations from S-shaped growth with the highest auto-correlations, which are found at time-lags of 1, 27, 34 and 45 years. It suggest that the periods of the cycles for growth are not so regular and harmonic as was estimated for *Figure 1*. Probably this is caused by the shift of the pattern during World War II. Anyhow these lagged observed slope deviations from before 1969 are used for the prediction up to 1994 and subsequently those from before 1995 for the prediction after 1994.

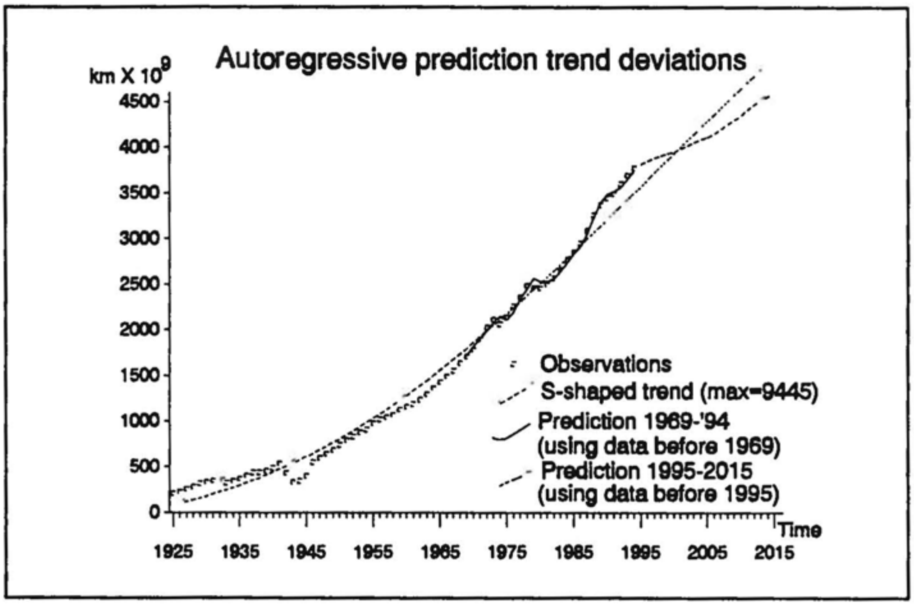

Figure 4. *Auto-regressive prediction of kilometre growth in the USA.*

The correlation between observed and predicted growth from 1969 to 1994 inclusive is 0.9972. The explained variance with respect to predicted growth by the S-shaped function only is significant (F-test=33.10; 23 and 19 df). Comparing *Figures 1* and *4* we see that the latter predicts better, especially during recent and oil crises years. In view of the retrospective fit the different regression prognosis after 1994 seems more reliable.

The highest auto-correlations for deviations from the exponential fatality rate are found for time-lags of 1, 35, 20 and 44 years. It sustains the harmonic cycles estimation for *Figure 2*. In accordance with theory, we also find several high cross-correlations of slope deviations from the exponential fatality rate with lagged slope deviations from S-shaped growth as well as with lagged local slope differences for growth. These cross- and autocorrelations are used for the prognoses shown in *Figure 5*.

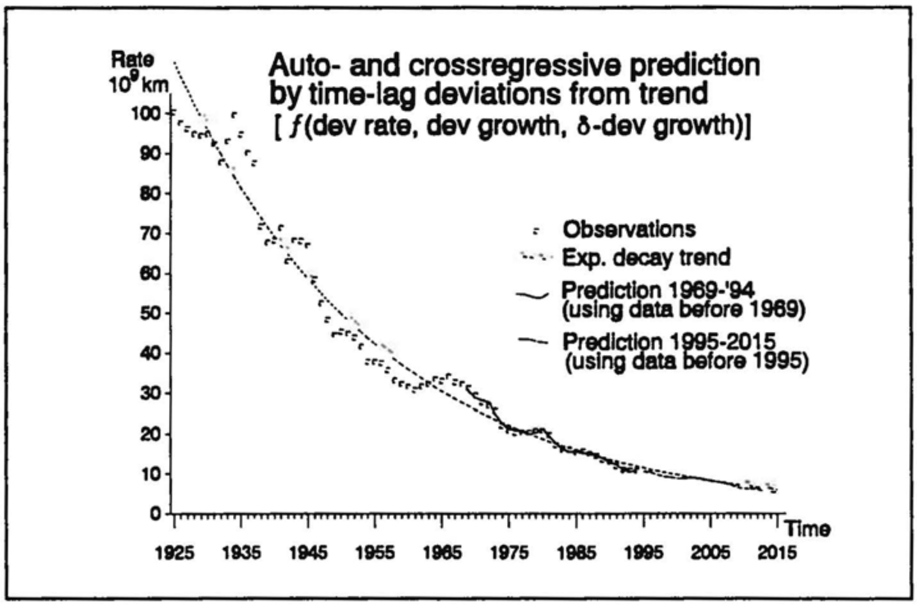

Figure 5. *Cross- and autoregression prediction of fatality rate in the USA.*

The retrospective prediction from 1968 to 1994 again only uses data from before 1969, while the prognosis after 1994 only uses the dat from before 1995. The retrospective prediction is more accurate than the fit by exponential decay and cycles of *Figure 2*. Both predictions are similar. Apparently the pattern around exponential fatality rate in the USA is not as much disturbed by World War II as the traffic growth pattern.

The correlation between observed and predicted fatality rate for 1969 to 1994 inclusive is 0.9770, while the explained variance with respect to the prediction by exponential decay only is very significant (F-test 14.04, 24 and 13 df). Compared to the extrapolation of exponential risk decay with cycles in *Figure 2* the prognosis after 1994 of *Figure 5* shows a similar, but less rising fatality rate around 2005.

Due to the rather accurate predictions for 1969 to 1994 inclusive of vehicle kilometres (*Figure 4*) and fatality rate (*Figure 5*) the product of these predictions as the predicted fatalities for 1969-1994 are remarkably close to the actual observed fatalities as is shown in *Figure 6*.
Here the retrospective prediction deviates by an average Chi²-contribution of 32.2 for the period 1969-1994 and is much more precise than the one of *Figure 3* with an average Chi²-contribution of 330.0 for the period 1923-1994. In comparison with the extrapolation in *Figure 3* we see that a lower level and a more declining development of fatalities is now predicted for the USA in the next century.
In *Figure 6* we also plotted the product of the underlying curves for S-shaped growth and exponential risk decay as the underlying main trend of the fatalities that has its maximum around 1970. As can be expected the regression method predicts a future development of fatalities that deviates less from that underlying main trend than the prognostic prediction by the product of curve extrapolations for growth traffic and fatality rate shown in *Figure 3*.

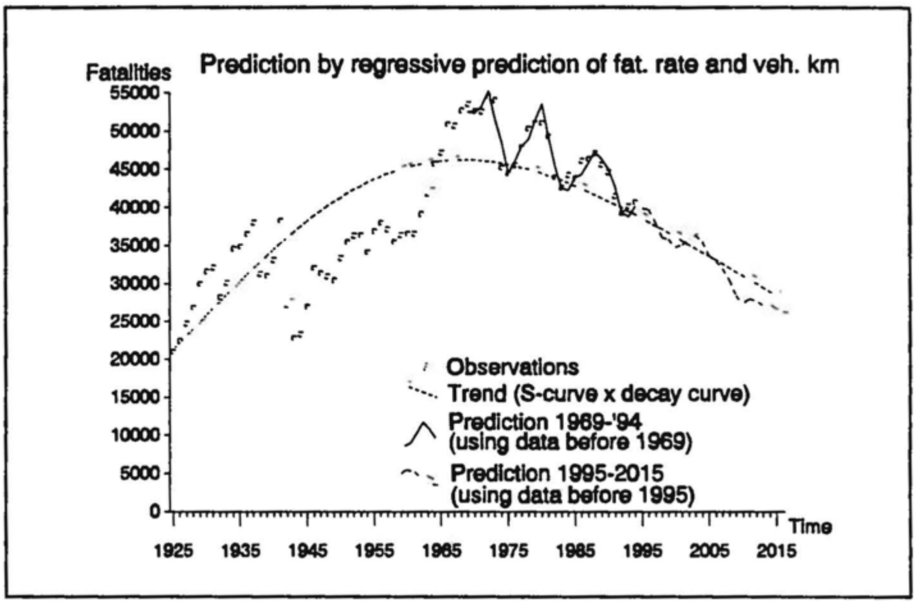

Figure 6. *Fatalities in the USA (product of graphs from Figures 4 and 5).*

2. Analyses for Latin-American and Caribbean countries

The model analysis of traffic growth and risk has shown to be valid for time-series from many other motorised countries than the USA. It also is used as a method for the future prognosis of road traffic and safety in the newly motorising countries of Central-East Europe (Koornstra, 1992b) and South-East Asia (Koornstra, 1993). Here, we analyse the data from some Latin-American countries as examples of the road traffic and safety developments in Caribbean and Latin-American countries. In particular we analyse the data from Brazil, an already somewhat motorised country, and Chile as a newly motorising country. For other countries we could not obtain pairs of long enough or consistent time-series for fatalities and traffic volumes to warrant a reliable analysis. For Brazil and Chile we use the motor vehicles annually in use (without motorcycles), because long time-series of kilometres could not be obtained for these countries. Since national transport data (even annual kilometres) are sometimes available, it might be an indication for the low priority of road safety in Latin-American and Caribbean countries that the road fatalities often are not registered on a national level or only relative recently so. Anyhow, for our analysis we need rather long and continuous pairs of time-series for fatalities and motorised traffic. In fact from the international documents (IRF, 1966-1994) we only obtained such time-series for Brazil and Chile.

2.1. Analysis for Brazil

The available time-series on both fatalities and motor vehicles for Brazil from 1968 to 1993 inclusive is a rather short series for a trustworthy analysis. The motor vehicle growth in Brazil seems up to now still more or less exponential increasing. Therefore, the future saturation level of motor vehicles can not be estimated from the data.

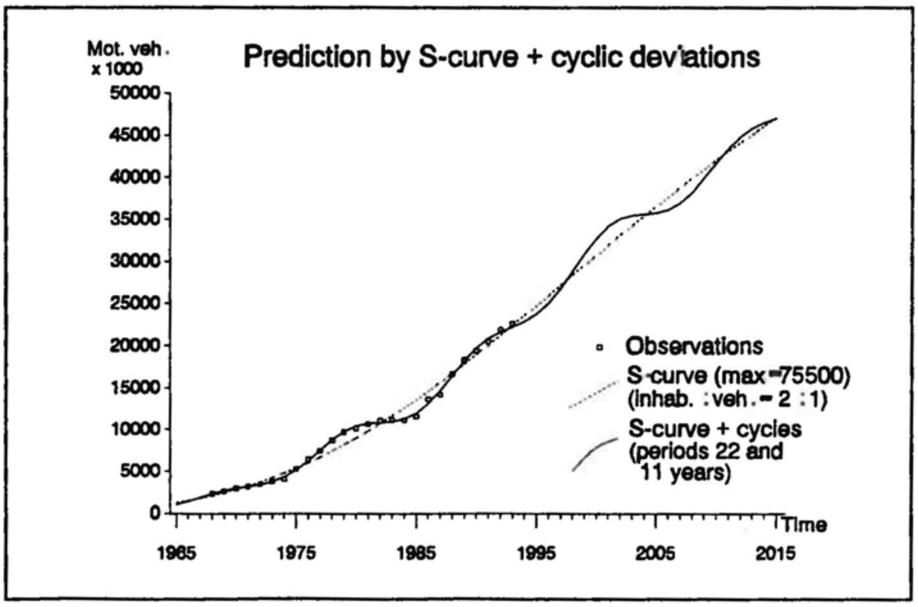

Figure 7. *Motor vehicle growth in Brazil (Gompertz curve with cycles).*

For very different maxima the fit for the past 26 years is nearly equally well predicted. So we a priori have to determine the maximum for saturating motorisation in the far future. We chose the maximum to be alternative saturations at either two or four present inhabitants per motor vehicle. *Figure 7* shows the result for the rather acceptable high motorisation level of 2 inhabitants per motor vehicle. For the 151 million inhabitants of Brazil it means a maximum of 75.5 million motor vehicles. The level of motor vehicles in 1993 is 22.6 million. In view of the present motorisation level of nearly 6.5 inhabitants per motor vehicle and the past growth a saturating motorisation level of 4 inhabitants per motor vehicle seems unlikely low. From *Figure 7* we see that there is a cyclic deviation pattern from still nearly exponential growth. The optimally fitted cycles have periods of 22 and 11 years with a larger weight for the latter. The fit gives a correlation between predictions and observations of 0.9989.

The analyses of fatality rates and fatalities for Brazil may be questioned. The Brazilian data from the IRF-World Road Statistics give unbelievable low fatality rates. It nearly reaches 0.25 per 1000 motor vehicles in 1993. Even the most safe and highly developed countries, like Great-Britain or the USA, did not have such a low fatality rate at times their degree of motorisation was even higher than in Brazil nowadays. Although the time-series of fatalities seems consistent, we conjecture that its actual level is considerably higher. Informal information indicate that the present level of road fatalities in Brazil may be over 20 thousand. Therefore, the absolute level in the next two figures for the analyses of fatality rates and fatalities in Brazil perhaps ought to be multiplied by about a factor 4. Since the time-series are consistent we assume, however, that the course of the developments for fatality rates and fatalities (apart from their levels) still may be meaningful.

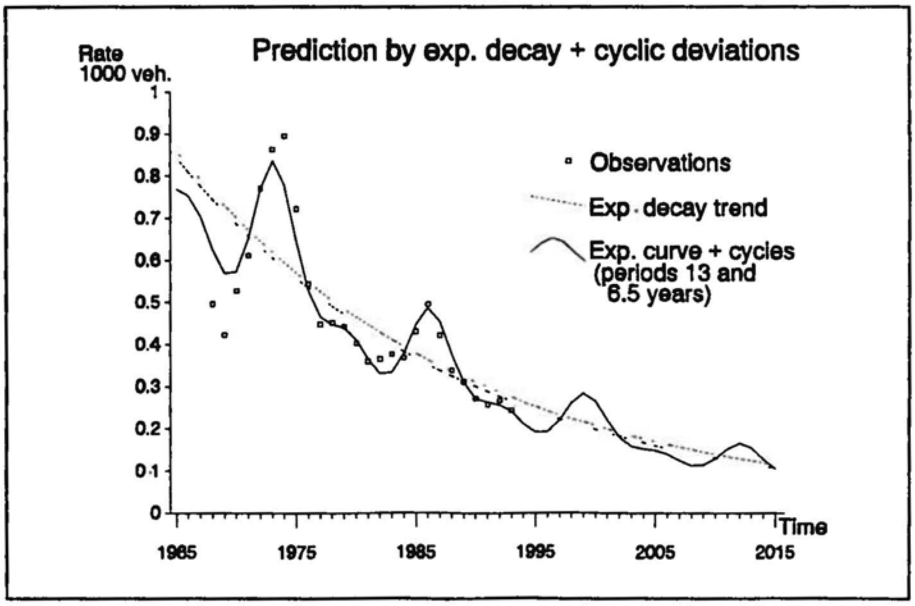

Figure 8. *Fatality rate in Brazil (exponential decay with cycles).*

Anyhow, *Figure 8* shows the analysis for the fatality rates obtained from the IRF-publications. The best fitting harmonic cycles around exponential decay have periods of 13 and 6.5 years with a larger weight for the cycle with a 13 year period. It only fits the begin period less well. The correlation between observed and predicted fatality rates is 0.9783. The underlying exponential decay corresponds with a rate reduction of 4.1% per year. However, marked peaks of rising fatality rates are observed, which are fitted by the cycles for deviations from exponential decay.

The product of the graphs from *Figure 7* and *8* predicts by definition the fatalities as published by the IRF (but possibly an actual factor 4 higher). This product is shown in *Figure 9* together with the published fatalities.

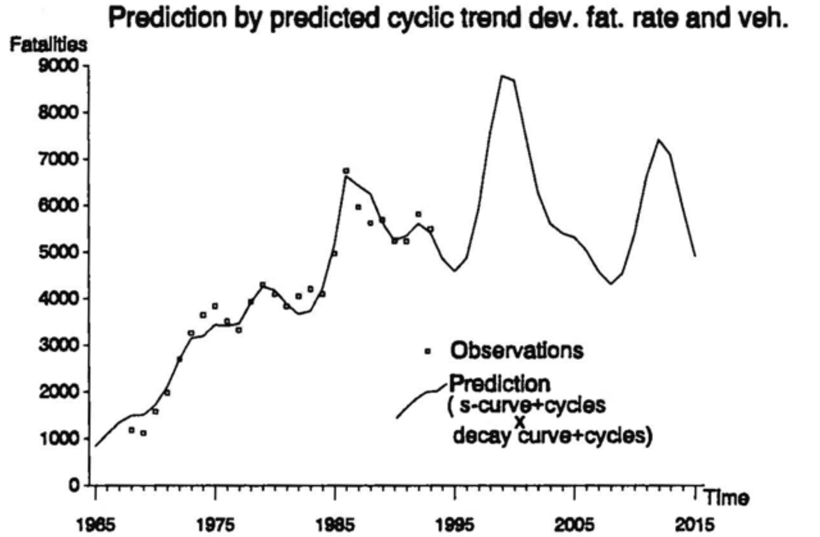

Figure 9. *Fatalities in Brazil (product of predictions from Figures 7 and 8).*

The fit of the retrospective prediction seems quite acceptable and has an average Chi²-contribution of 20.5. The extrapolation of the time dependent curves from *Figures 7* and *8* also determine the prediction of the future development of fatalities in Brazil (also possibly a factor 4 higher in reality). Due to the cyclic increases in the fatality rate and cyclic additional increases of motor vehicles its prognosis shows marked peaks of rising fatalities (up to nearly 9 thousand fatalities or by the conjectured factor 4 perhaps actually 35 thousand fatalities in 2000), while no declining trend in the annual fatalities is visible in next two decades. This prediction amounts to a total of about 130 thousand fatalities between 1995 and 2015 in Brazil (possibly even over half a million fatalities, if the correction factor of 4 for the actual level is applied). However, this prediction is rather uncertain and surely not reliable for a 20 year future prognosis, due to the relative short time-series available for the analysis.

Although the available time-series for Brazil is too short for a test of the predictive analysis by the regression method (long time-lags can not be considered due to the lack of data before 1968), we have performed the regression prediction for Brazil in the same way as for the USA in section 1.3. We only show the prediction of fatalities by this regression approach based on the regression predictions of motor vehicle growth and fatality rates. For a prediction period from 1982 to 1993 inclusive we used the slope deviations from the underlying trends for the data before 1982. With time-lags limited to only 13 years it still yield a rather excellent prediction with correlations of 0.9906 and 0.9983 for motor vehicles and fatality rates respectively. The alternative prediction of fatalities for Brazil, obtained from the multiplication of these regression predictions of motor vehicles and fatality rate, is shown in *Figure 10*. Since the fit give an average Chi^2-contribution of only 9.61 for the prediction between 1982 and 1993, it may indicate a more valid prediction for the future by this methodology.

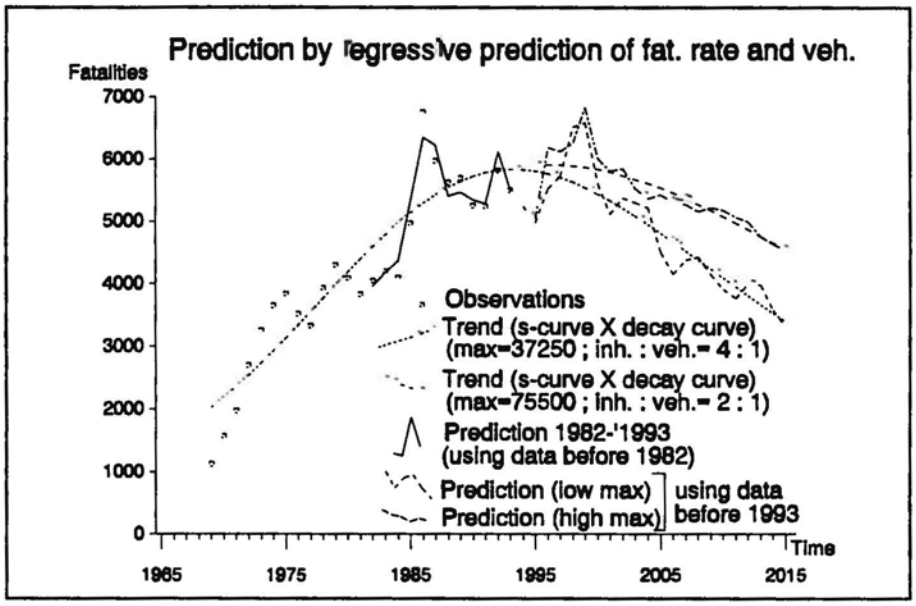

Figure 10. *Fatalities in Brazil (product regression pred. of veh. and rate)*.

Two prognostic predictions for the earlier mentioned two alternative saturating levels of motorisation are shown in *Figure 10*, both based on the regressions of the data before 1994.
However, the different saturation levels of motorisation are not very crucial for the prediction of the fatalities up to 2005. Thereafter the more likely higher growth to 75.500 thousand motor vehicles is also accompanied with higher predicted fatalities. Also the underlying macro-trends for the fatalities, obtained from the S-shaped growth and exponential decay of risk only, are shown for both end-levels of motorisation in *Figure 10*.
The maximum fatalities for the higher underlying trend based on the higher degree of saturating motorisation lies towards the end of the century. There, also the highest annual number of nearly 7.000 fatalities is predicted (with the possible correction factor of 4 perhaps actually about 27.000 fatalities in 1999). As for the USA the prediction for Brazil by the regression method also tends to approach the underlying trend more closely in the long run than the prediction by the curve product extrapolation method of *Figure 9*, where the peaks in fatalities are much higher.
From this regression prediction a declining trend of fatalities is indeed already visible for the next century. Nonetheless, still it predicts a total of about 110 thousand fatalities between 1995 and 2015. With the correction

factor of 4 for the actual number of fatalities it would amount to more than 440 thousand fatalities on the Brazilian roads in the next two decades.

2.2. Analysis for Chile

For Chile we have a pair of time-series for fatalities and motor vehicles from 1964 to 1990 inclusive. The motor vehicle growth up to 1990 also is still more or less exponential and no saturation level can be determined from the data. Therefore, again a saturating motorisation of either four or two inhabitants per motor vehicle are a-priori assumed. Chile has now about 13.8 million inhabitants, so the alternative maximum levels assumed for the analysis are taken to be either 6.900 or 3.450 thousand motor vehicles.

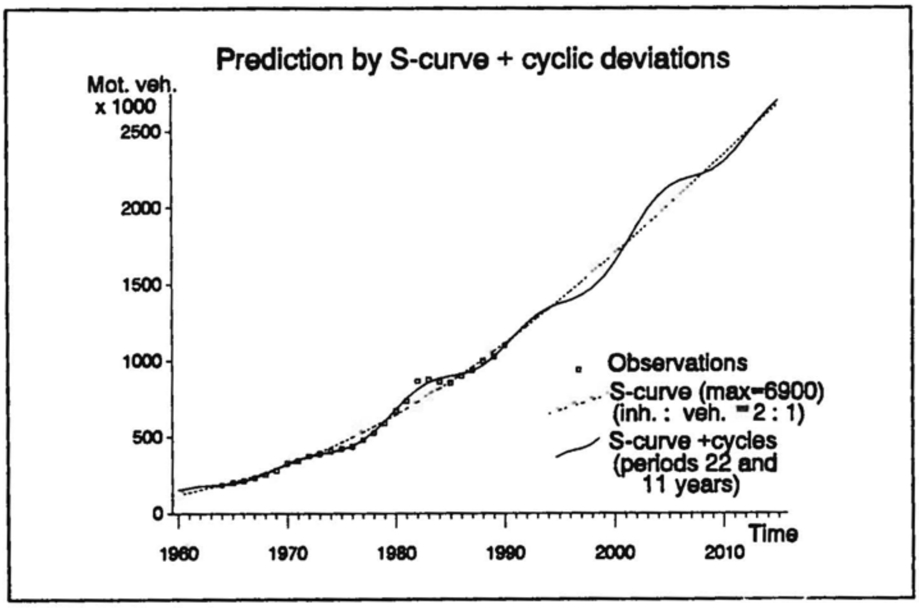

Figure 11. *Motor vehicle growth in Chile (high max. Gompertz curve with cycles).*

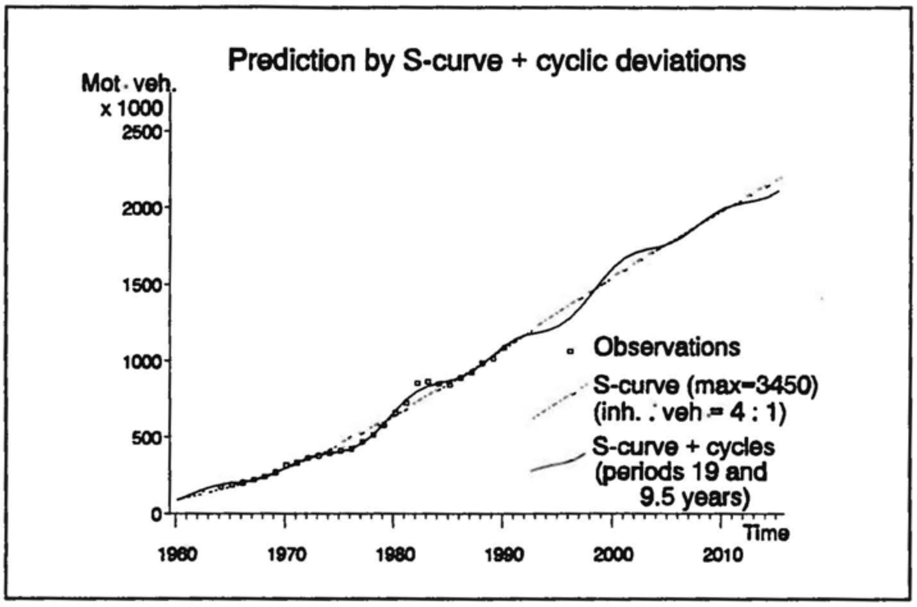

Figure 12. *Motor vehicle growth in Chile (low max. Gompertz curve with cycles).*

Figures 11 and *12* display the underlying S-shaped growth together with a simultaneously fitted pattern of harmonic cycles for each alternative.
Also the observed motor vehicles of Chile show that there are deviations cycles from S-shaped growth. The best fit for *Figure 11* yields harmonic cycles with periods of 22 and 11 and for *Figure 12* these cycles have periods of 19 and 9.5 years. The two retrospective predictions fit nearly equally well, since the correlations between observed and estimated growth are 0.9978 and 0.9980 for *Figure 11* and *12* respectively.

The fatality rate for Chile is also fitted by exponential decay with cycles as for the USA (*Figure 2*) or Brazil (*Figure 8*). However, here the results of the analysis depends on the number of harmonic cycles fitted.

Fitting the fatality rates by exponential decay and three harmonic cycles, as for the USA significantly is needed, we find a moderate slope for the underlying exponential decay with an annual reduction percentage of only 3.65% with optimal cycle periods of 36, 18 and 9 years. Although a time-series of 27 years is somewhat too short for a well determined cycle of 36 years, the fitted cycle periods are nearly the same as for the USA. For Chile, however, the influence of the 36 years cycle is very large as *Figure 13* illustrates. Due to the large influence of the 36 year cycle its extrapolation around the moderate decay curve yields a predicted fatality rate that even rises from 1.4 in 1990 to nearly 1.9 in 2000.

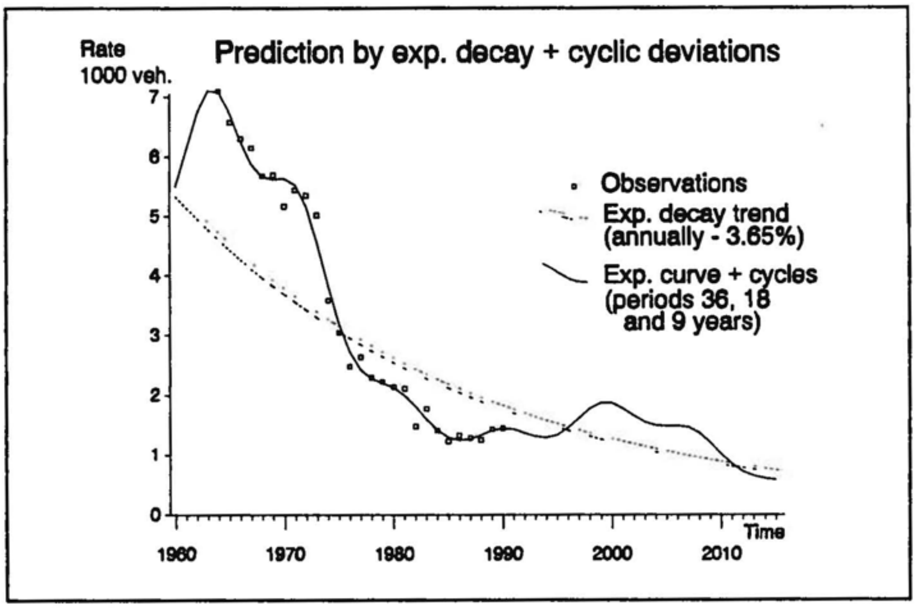

Figure 13. *Fatality rate in Chile (moderate exp. decay with 3 cycles)*.

For only two cyc les fitted, which may be more appropriate for time series of only 27 years (as for the 26 years of Brazil), we find a rather steep slope for underlying exponential decay with an annually reducing fatality rate by even 7 5% and optimal cycles of 18 and 9 years periods with only moderate influence. This alternative is shown in *Figure 14*.

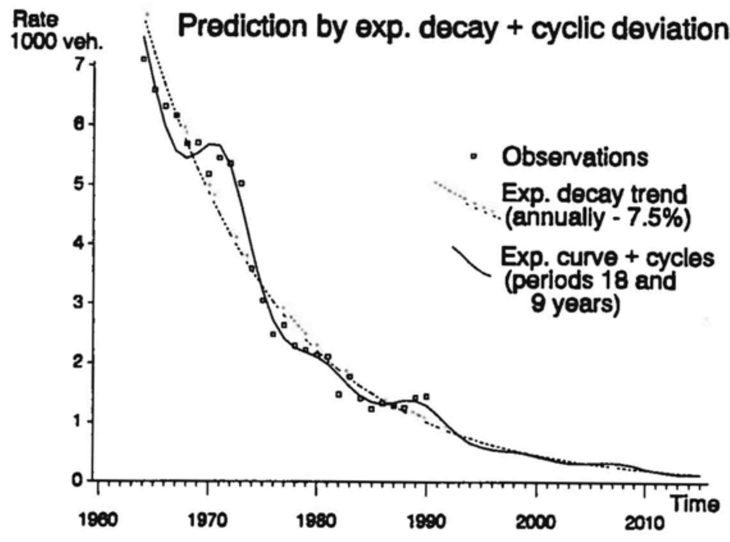

Figure 14. *Fatality rate in Chile (steep exp. decay with 2 cycles).*

Clearly the extrapolation of this alternative with a steep exponential decay, shown in *Figure 14*, will predict a much more positive future development for the road safety in Chile. However, the retrospective prediction of *Figure 13* fits better than the one in *Figure 14*. Multiplication of the predicted fatality rates by the observed annual motor vehicles gives deviations from the observed fatalities which amount to $Chi^2=155.6$ for *Figure 13* and to $Chi^2=208.1$ for *Figure 14*. The F-test ($F=1.34$ with 20 and 18 df) for the difference, however, is not significant.

The two alternatives for growth of motor vehicles (high and low saturating maximum) combined with the two other alternatives for the fatality rate (moderate and steep underlying exponential decay) makes four alternative possibilities for the prediction of fatalities. As expected from the fits for *Figure 12* (slightly better) and *13* (much better) the combination of low saturating growth and moderate slope for the underlying exponential decay yields the best retrospective fit, but the retrospective fit of each other alternative is not significantly worse. Nonetheless, the alternative prognostic predictions of the fatalities for the combination with a moderate or a steep exponential decay of the fatality rate are quite different. This is shown in *Figures 15* and *16*. In *Figure 15* the prognoses for the combinations of a low and a high maximum motor vehicles with a moderate decay of fatality rate are both shown for the future. Only one retro-prediction is shown, since the retrospective differences are too small.

The multiplicative combination of *Figure 12* (low maximum growth level) and *Figure 14* (steep fatality rate decay) clearly must give the most optimistic prognosis for the fatalities of the future in Chile. This alternative prediction is presented in *Figure 16*.

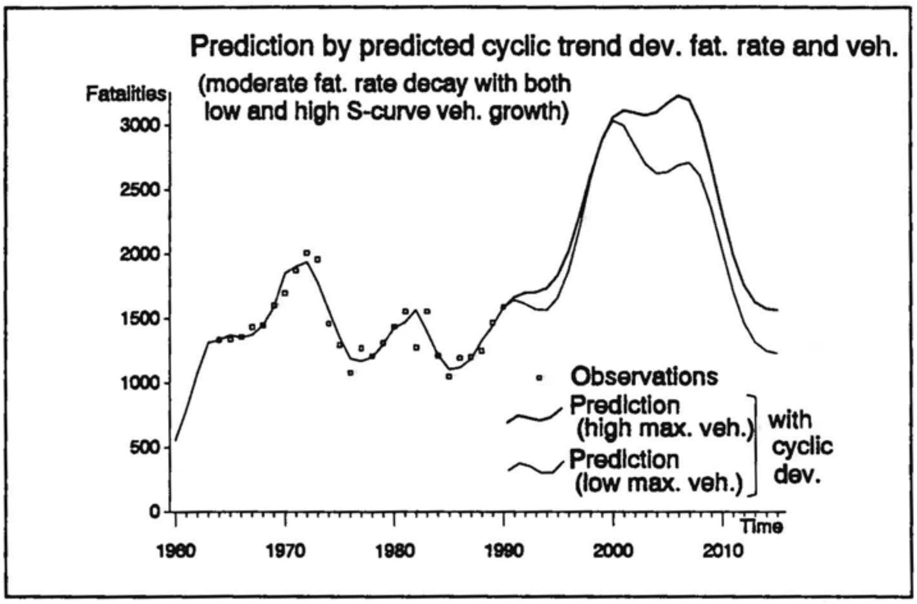

Figure 15. *Fatalities in Chile (low and high max. growth; moderate exp. rate decay).*

As can be seen from the two prognoses of *Figure 15* in comparison with the prognosis of *Figure 16*, the future development of fatalities in the next two decades is much more influenced by the difference in predicted decay of the fatality rates than by the different maximum levels for the prognoses of the motor vehicle growth.

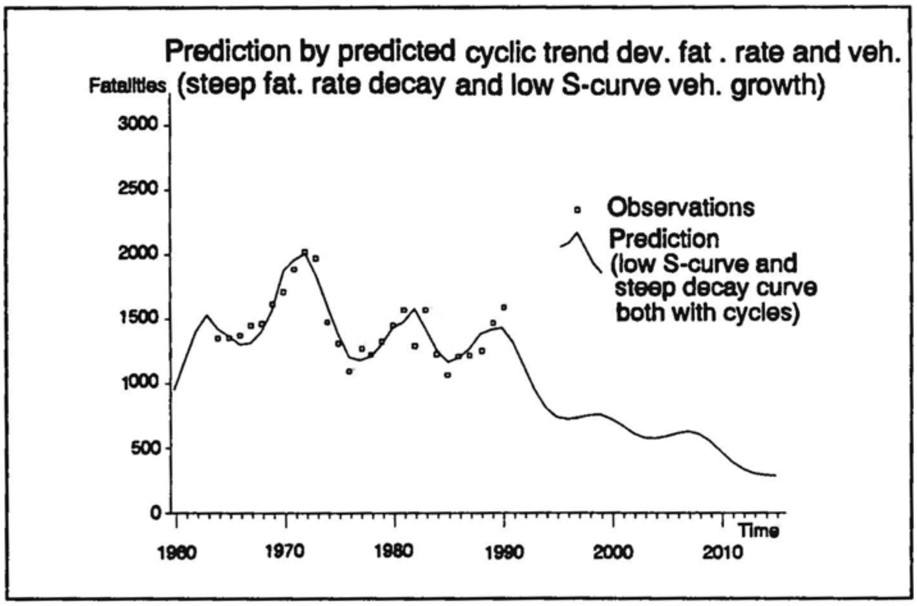

Figure 16. *Fatalities in Chile (low max. growth, steep exp. rate decay).*

Since recent information from Chile indicates that the fatalities after 1990 have increased, the alternatives with the better fitting moderate decay of the exponential fatality rate (*Figure 15*) regrettably may be more justified. Therefore, it must be concluded that it is of utmost and crucial importance to develop such an effective road safety policy that the fatality rate will show a steep decay. Otherwise the traffic growth in Chile will result in an increase of the number of road fatalities by even more than 100%.

2.3. Total prognosis for Latin America and Caribbean region

For those countries in Latin America and Caribbean region that nowadays register fatalities and motor vehicles the most recent fatality rates seem to range from about 3.0 to 0.5 or to 0.25 if the IRF-publication for the data of Basil is correct. We deduce from the recent IRF-publication for 1990 to 1994 and some additionally obtained statistics the following national fatality rates per thousand motor vehicles (motorcycles excluded):

Ecuador	3.0	Honduras	2.9
Nicaragua	2.9	Colombia	2.1
El Salvador	2.0	Argentina	1 6
Chile	1.5	Brazil	0.25 (or 1 0)
Costa Rica	0.8	Mexico	0.5

From these figures and national data on motor vehicles we conjecture for the total of the 35 Latin-American and Caribbean countries that about 50% of the motor vehicles is driving in regions with a narrow fatality rate range around or close above a medium value of 0.5 (mainly in Mexico, Brazil and Costa Rica). About a further 25% is driving in regions with a narrow fatality rate range around or close above a medium value of 1.5 (mainly in Chile, Argentina and comparably motorised countries), while the last 25% drives in still less motorised regions with a fatality rate around a medium value of 2.5. It yields an estimated underbound for the mean fatality of the 35 Latin-American and Caribbean countries of 1.25.

The estimated total motor vehicles in the 35 Latin-American and Caribbean countries is 50 million, based on the enquiry made for the OECD road safety conference in Sao Paulo. So by the minimum mean fatality rate of 1.25 the estimated total number of annual road fatalities in these 35 countries will be at least about 62.500 per year in the recent years.

The total population in Latin-American and Caribbean countries is estimated to be 450 million in 1995. With an annual population growth of nearly 3% the population will be about 600 million in the year 2015. Also assuming a continuation the present average of 6% to 7% annual increase of motorisation, the level of motorisation will grow to about 3.5 inhabitants per motor vehicle in 2015. Combining these rather realistic assumptions the estimate of the total motor vehicles in the year 2005 is about 110 million and in 2015 about 175 million.

By a low average fatality rate decay per year of 3.0% (the lowest to be observed in the world, but also nearly the average decay in the USA) the mean fatality rate will become 0.92 in 2005 and 0.68 in 2015. The estimated total of road fatalities in the 35 Latin-American and Caribbean countries with a growth to 110 million motor vehicles in 2005 then amounts to 100 thousand per year in 2005 and with a growth to 175 million motor vehicles in 2015 to about 120 thousand per year in 2015.

Alternatively, by a rather steep average fatality rate decay of 8% (the highest to be observed as for the safer Nordic and North-West countries of continental Europe, but also in Chile between 1964 and 1984) the fatality rate becomes 0.54 in 2005 and 0.235 in 2015. Given the estimated number of motor vehicles in 2005 and 2015 for the 35 countries of Latin America and Caribbean region the total road fatalities then would decrease to 59 thousand in 2005 and to nearly 40 thousand in 2015.

So depending on a minimal or maximal effectiveness of road safety policies in reducing the fatality rates in the Latin-American and Caribbean countries the road safety situation will lead in the next 20 years to either a worsening or improving state of affairs. It means either an increase to nearly 100% more road fatalities (from 62.500 in 1995 to 100.000 in 2005 and 120.000 in 2015) or an eventual improvement of road safety by about 35% (first a small increase from 62.500 in 1995 to 65.000 at the end of this century and then decreasing to 59.000 in 2005 and to 40.000 in 2015). Between 1995 and 2015 in the 35 Latin-American and Caribbean countries it amounts to totals of either nearly as much as two million fatalities or somewhat above one million fatalities. That difference of nearly a million people less killed in road traffic also implies probably 50% less otherwise expected damage and injury accidents.

In the European Union with an annual total road fatalities of 50 thousand the macro-economic costs of all road accidents are estimated to be more than hundred billion US-dollars per year (Gerondeau et al, 1991). Correcting by the ratio of the respective gross products per inhabitant the mean accident costs in Latin-American and Caribbean countries are nearly 20% of the European accident costs. So the macro-economic savings from one million prevented fatalities, inclusive the also prevented damage and injury accidents, amount to about 400 billion US-dollars in the next twenty years. Investments of twenty billion US-dollars per year would then be justified for an achievable prevention of these otherwise expected additional road accident damages, injuries and fatalities.

3. Structural road safety improvements

One lesson from the road safety prognoses is that we should control the growth of road traffic. However, for economic reasons and especially in democratic countries with a free market economy the traffic growth is very hard to influence. As our analyses have shown road traffic growth can be seen as an autonomous process in conditions where motorisation has become to evolve. The only real alternative for a positive development in road safety, as our model analyses have shown. is a larger annual reduction in fatality rate. This only can be established by road safety improvements and investments in road safety. Although it is not the aim here to review the effectiveness of road safety measures a brief summary of effective strategies for road safety improvement may be in place.

3.1. Transport modes

Motorisation changes the transport system, but the road transport system has never been designed in such a way that the opportunities for accidents are prevented a priori as it has been for rail- and air-transport. Rail and air passenger transport are at least 200 times safer than the European road transport. Surely a higher factor will be in place for the risk comparison with the Latin-American and Caribbean road transport.

Mode	Area	Fatalities/pass. km
Road	EU	$3.3x10^{-8}$
Rail	West EU	$1\ 6x10^{10}$
Air	USA	$0.4x10^{-10}$

Table 1. *Risk per transport mode*.

Some parts in Latin-American and Caribbean countries have a relatively developed rail system. In view of the need of a safe transport it is of great importance to maintain and enhance that mode of passenger transport in the future. In contrast to North American policies in Europe high speed trains for intercity passenger transport at distances up to 600 km or more and intra-city rapid rail systems are seen as essential elements of the national transport policies. Systems for high speed trains and rapid rail transit can be optimised to economic viable systems. An increased share of passenger transport by rail in the Latin-American and Caribbean countries will also help to control the growth of road traffic. It partially also may prevent the possible problems of increasing congestion in the future on motor freeways and in large cities. Above all it certainly would contribute much to overall transport safety.

Since motorised two-wheelers have the highest fatality risk a road safety policy under growing motorisation must be directed to a reduction of the share of motorised two-wheel vehicles. Economic growth allows for its replacement by modern safe cars, while the reduction of its relatively large share in some Caribbean and Latin-American countries surely will contribute a further marked reduction of the fatality rate.

3.2. Road infrastructure

Despite the gradual upgrading of the road system it everywhere still is a network of roads that concatenates of a nearly endless variety of road sections by an also endless variety of cross-connections. The result is a road system that is too complex for the road user to allow reliable predictions for the next oncoming situation. Only the modern motor freeways permits relative reliable predictions. Since this road category is well predictable (extra shoulder lane for emergency stops, no level junctions and no opposite traffic). Because the variation in speed is relative low (only motorised traffic) it also is a relative safe type of road, in spite of the high speeds driven. A comparable high level of safety holds for residential traffic calming areas, where speeds are so low that speed variation between all road users is also low, which allows for enough reaction time to prevent serious accidents.

As can be seen from the next table of injury and fatality rates on Dutch roads, all other road types than motor freeways and residential traffic calming areas have considerable higher injury and fatality rates. The lack of safety varies with the combination of maximum speeds and amount of discontinuities by level junctions and opposite traffic (high opportunity for dangerous conflicts) as well as by presence or absence of mixed slow and fast categories of road users on the road type (causing large variations in speeds). The rural roads have the highest fatality rate and the urban arterials the highest injury rate. For Latin-American and Caribbean countries such detailed data are not available. However, the ratios between the risks probably will be similar for comparable road types in Latin-American and Caribbean countries. The applicable risk levels will be much higher, because the Netherlands has one of the world's most safe road networks (fatality rate of 1.2 in 1994 per 100 million km).

Road type	Max. km/h	Mixing fast/slow	Level junctions Opposite traffic	Injury rate 10^6 km	Fatality rate 10^8 km
calming area	<30	yes	yes	0.20	0.1
resid. street	50	yes	yes	0.98	1.4
urban arterial	50/70	yes/no	yes	1.07	1.7
rural road	80	yes/no	yes	0.40	2.5
rural motor road	80	no	yes	0.28	2.0
motorway	100	no	no/yes	0.07	0.6
motor freeway	100/120	no	no	0.06	0.4

Table 2. *Injury and fatality rates for road types in The Netherlands, 1992.*

Enlargement of the road network by motor freeways in the Latin-American and Caribbean countries will be necessary for reasons of the increasing road transport needs. It also will redistribute the traffic towards this safer road type and away from the dangerous rural roads. This in itself would have a large positive effect on the reduction of the fatality rate.

The road safety in built-up areas could be improved markedly by the construction of by-pass roads around villages and towns for the otherwise trough-going traffic. Road safety in residential area itself can benefit tremendously by the introduction of traffic calming areas and pedestrian zones in towns and large villages. Evaluations show that reconstruction to calming areas can reduce 90% of the injury accidents. *Table 2* reveals for calming areas in comparison to residential streets an 80% reduction in injury accident rate and a much higher reduction in fatality rate.

The redesigning of the road categories between motorways and residential calming areas to a limited number of categories of self-explaining roads with well predictable uniform layouts of routes and crossing types for an orderly and safe traffic flow is most urgent. This is the major long term task which should be undertaken in a national coordinated way, since design diversity between roads with the same function and road design diversity between regions contributes to unpredictability and hence to a higher lack of safety.

Infrastructural separation of slow traffic (non-motorised) and traffic of fast (motorised) or heavy vehicles is one of the safe design principles which should be applied where possible also in Latin-American and Caribbean countries. This means pedestrians on sidewalks only and preferably cyclist on separated cycle paths. Safer road constructions and a reordering of traffic for these vulnerable road users can very much reduce the fatality rate, especially in Latin-American and Caribbean regions with a large share of non-motorised road user fatalities. Research with respect to road crossings has shown that the uniform layout of junctions by roundabouts with priority for roundabout traffic is a much safer level crossing than non-signalised as well as signalised junctions, especially in built-up areas. Reductions by 90% of injury accidents are observed after reconstruction of residential junctions to roundabouts. The relative low share of car-car accidents in the fatal accidents of the UK may be explained by the dominant application of roundabouts in the British road network.

There is a long way to go before such a renewed and safe road system will be established. The first step is conceptual: a functional hierarchy of road categories with a functional standard design over the whole network.
The second step is the clarification of its safety principles on a nation wide level by the preparation and dissemination of reference material to the road authorities, since the standardised design principles for a safety upgrading to the road network ought to be applied by all road authorities. The last and most expensive step is the building of new roads and the reconstruction of the existing roads according to these standardised safety principles as well as an improved maintenance of the redesigned road network.

3.3. Road user behaviour

Driver education is a prerequisite, but different driver licensing requirements have not shown that road safety is very much influenced by these differences. The risk for novice drivers is high, but drops the more kilometres are driven by the driver. The risk level only stabilises on a lower level after more than fifty-thousand kilometres experience. Apparently safe driving can only be learned by much practice. Only prolonged learning periods in easier circumstances (by means of a graded licensing, curfew laws and accompanied driving before full licensing) have shown to yield positive effects on road safety.

Information campaigns for road safety, especially those which are not directed to specific behaviours and/or are not sustained by intensified police enforcement, are not or only temporarily effective.

Lack of seat belt wearing, overspeeding and drunken driving, however, are main behavioural areas where road safety can be improved effectively.

Seat belt wearing has shown to have a preventive effect of about 40% on the risk of a fatal outcome from a car accident (Evans, 1991). Permanent actual enforcement of seat belt laws by fines at every kind of police control for persons not wearing a seat belt combined with recurrent public information is the effective measure that has enhanced compliance to nearly 100% in countries where compliance was below 50%.

The level of blood alcohol while driving has an exponential increasing effect on the risk of casualty accidents, as the often confirmed study of Borkenstein (Evans, 1991) has shown. For example the fatality risk with 1.2 promille blood alcohol is about six times higher than for sober drivers.

A proportional reduction of the mean speed has a double quadratic effect on the proportional reduction of fatalities (Nilsson, 1982). For example, this means that a 10 % reduction in mean speed (0.9) will reduce the fatalities by 35% (0.9^4=0.65). Also differences in speed contribute to higher risks. Deviations from the mean speed driven on highways are parabolic related to the risk of accidents (Solomon, 1964: Cirillo, 1968). Mean speed is more related to the severity of accident outcomes and speed variance to the frequency of accidents.

Adequate speed limits and homogenisation of speeds are both very important for road safety. Because of the relation between the speed distribution (mean and variance) and road safety and also because the share of modern fast passenger cars is increasing in developing Latin-American and Caribbean countries the speed limits for their roads in built-up areas and rural roads should not exceed respectively 50 and 80 km/h.

Intensified efficient police enforcement by automatic devices (speed violations) or by visible controls of randomly selected road users on unpredictable places and times (driving under influence of alcohol), have shown that road safety can be improved markedly (Koornstra, 1992b) especially when the enforcement is combined with targeted information campaigns. The few examples of markedly intensified enforcement (in some states of Australia) show that large effects on the reduction of fatalities (up to 50% less within two years) are to be observed when the intensity level of enforcement becomes above one out of three license holders controlled on alcohol annually and more than three speed controls per license holder within one year.

4. Conclusion

The present total number of annual road fatalities in the 35 Latin-American and Caribbean countries is estimated to be 62.5 thousand. The prognostic predictions of the road safety level in the Latin-American and Caribbean countries are rather alarming. The toll for the growth of motorised road traffic in the total of the Latin-American and Caribbean countries even may become about 120 thousand fatalities per year in the second decade of the next century, unless there are effective road safety policies established and investments in road safety made. However, even by the most effective road safety policies it will be difficult to reduce the total road fatalities to less than 40 thousand per year before 2015.

Nonetheless, national and regional efforts for an effective road safety strategy (infrastructural road safety improvements, prolonged driver training and intensified police enforcement of appropriate road safety laws as well as the promotion and offering of other safer modes of passenger transport), can reduce the loss of the otherwise predicted additional total of about one million lives in the next twenty years. It would not only prevent the grief over them, but also prevent the human suffering caused by millions of otherwise additionally expected injury accidents. Moreover, it also could save the waste of the huge additional costs involved in the otherwise not prevented damage, injury and fatal accidents.

The macro-economic savings that are achievable by the most effective road safety policies are estimated to be 400 billion US-dollars for the total of the 35 Latin-American and Caribbean countries in the next twenty years. Investment in road safety pays off more than usually is assumed.

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