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Grey Systems Theory Time Series Prediction applied to Road Traffic Safety in Germany

Hosse, René S.*. Becker, U.*, Manz, H.*

*Institute for Traffic Safety and Automation Engineering, Technische Universität Braunschweig, Braunschweig, 38108 Germany (Tel: +49-531-391-66300; e-mail: [r.hosse; u.becker, t.kurczveil]@ tu-bs.de).

Abstract: Although Road Traffic Safety in Germany has improved over the last four decades, nowadays more than 3000 people per year die in a car accident. Due to that the European Union signed the Vision Zero aiming to zero deaths until 2020. This goal seems hard to achieve investigating latest data on road traffic accidents. Furthermore it is yet unclear what provisions should be undertaken by government or industry to improve safety. This research applies a Grey Systems Theory MGM(1,4) in order to predict the development of road traffic accidents in Germany until 2025 based on the market diffusion of electronic stability program (ESP). Grey Systems Theory has shown impressive results in various applications and has the benefit to correlate multiple time series. The findings exemplify that only minor improvements until 2025 are to expect, having around 2000 fatalities per year, and more provisions must be made to achieve the Vision Zero.

Keywords: Grey Systems Theory; Road Traffic; Safety; Prediction Methods; Discrete Time Systems

1. MOTIVATION

Since the 1970s road safety provision innovate detectably road safety and helped to save lives. In 1972 all 24.6 min. a passenger died in road traffic, whereas the TBF (time between failure, here: duration between accidents and fatalities) in 2013 improved up to 157.4 min. A causal link between the occurred improvements and provisions taken can be identify statistically significant for legislative actions: the introduction of speed limits on country roads, alcohol limit and conditional wearing of seatbelts caused a significantly lower number of accidents with fatal consequences in the German road transport system. (destatis 2014) The causality of other technological actions are less tangible; statistics show it is not clear whether a positive safety effect is achieved or not (Hosse et.al., 2015). Accordingly, safety effects are highly dependent on market penetration of an undertaken technological safety provision, the less vehicles with a certain provision are on the roads, the less the positive effect can be measured in statistics. Until nowadays, positive safety trends can be maintained, however it seems to be the balance of 3000 to 4000 fatalities per year becomes the output value of the German road transport system. New provisions must be found to realize 'Vision (Towards) Zero' and reduce fatalities to a minimum. (CARE 2014) (Gwehenberger 2006)

In particular, technical provisions, in the form of advanced driver assistance systems (ADAS), are seen as inhering a high potential of improving safety on roads. Taking driving obligations from the driver to the automated controller it is expected that fatalities and accidents will decrease significantly over time and market penetration. The research of Brühning and Seeck (2006) showed that the safety potential of active and passive safety provisions is not yet fully utilized, and the vehicle-specific actions can improve still improve safety. Especially autonomous driving is opportuning for fulfilling zero deaths on roads (Winner 2011). Numerous ADAS safety efficiency evaluation methods (e.g. rate effect by Volkswagen AG) underpin these statements (Wille 2012). In most cases, efficiency measures are calculated, using a simulative procedure in a micro- to mesoscopic perspective. Yet it is not possible to translate these microscopic measures to a whole transportation system and evaluate if, and when, a safety provision will take an actual effect in the system itself, measurable in macroeconomic statistics.

Therefore this research paper aims to providing a methodological framework of how a times series can be analysed and used for prediction combining the behaviour of multiple time series. As basis the number of accident events, including fatalities, heavy and light injuries in road traffic, as well as the market penetration rate of electronic stability program will be taken for analysis. Previous research by the authors exemplified the analysis making use of a so-called safety potential time series, which will not be used in this paper. This paper discusses more in detail the applied method and the experiences with it.

2. STATE OF THE ART FOR TIME SERIES PREDICTION

Generally, there are two types of approaches for time series prediction available: model-based and databased predication models. The first type uses quantitative models, like System Dynamics, and predict the behaviour of system by its inner structure and mechanisms. The second type uses mathematical calculation models sourced by empirical data. Those are seen in this paper as the traditional time series prediction

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methods. A third type is available, called hybrid times series prediction, which will be discusses in the future research demand.

2.1 Model-based prediction methods

The field of model-based approaches provides numerous examples of microscopic to mesoscopic modelling of various transport systems and, consequently, the prognosis of traffic safety. It makes use of different modelling approaches, most of them formal methods. (Schnieder u. Schnieder 2013) The problem with model-based approaches lies in the assumptions made within the models itself. If the mechanisms in the model are inaccurate, no confidence in the model can be guaranteed. (Sterman 2002)

The method System Dynamcis by J.W. Forrester (1969) provides numerous examples of modelling of traffic flows and safety dimensions, compare (Wen-Hui et al., 2008), (Minami et al. 2010), (Torres et al., 2012), and (Nachimuthu et.al., 2013). This considers usually mesoscopic effect-relationships, such as effects due to education, policies or drivers experience on accidents. Advanced macroscopic models can be found in (Wansart 2012), and (Kieckhäfer 2013), but the focus intensively of strategic implications for product portfolio design, than traffic safety.

A sound prediction model for traffic safety was developed in the BAST (Federal Highway Research Institute) report M224. The model is based on risk-metrics methods and differentiates in great detail accidents and possible causes, including demographic change and various transportation means. (BAST 2012) The models does not take if-this-than-that relations into account due to risk metrics, which is the benefit by model-based approaches in general.

2.2 Databased prediction methods

In research can be found primarily databased methods. Classic regression analysis methods are used generally. These mostly take a macroscopic perspective; however, there is no correlation or relation created to other time series. (Brüde 1995), (Hauer 2010) More elaborates methods, such as non-linear auto regression analysis or probabilistic methods, provide more valid results, but are only conditionally for simultaneous correlation with other time series suitable. (Son 2011) (Yannis 2011)

The method applied in this paper is Grey Systems Theory (GST): Developed by Deng (1982), GST is gaining attention for prediction of system behaviour in case of incomplete information systems. Where there is no complete information available about systems internal mechanisms and structures finds GST its application. It finds its origin in the theory of control parameters estimation. The benefits of GST is on the one hand in the high quality of prediction, and the other hand the fact that any number of time series can be correlated with each other and forecasting, ranging from 1 to n.

GST finds numerous applications in biology, sociology and economic science, now gaining more interest in engineering science. Applications for traffic safety predictions can be found in (Mao 2008), (Wang 2012) and (Omidvari 2014). The results of the named authors substantiate the application for authorization of the GST Road Safety forecasts. Therefore, GST is a promising approach to achieve the objectives of this research.

3. METHODOLOGY

GST finds various terms of description, thus the terminology needs to be clarified. The authors differ the following Grey models:

[M]GM(j,n[r]), where

- *[M]* is representing a modified Grey Model
- *GM* is the Grey Model itself
- *j* is the order of the applied differential equations
- *n* is the no. of time series inputted to the Grey Model, and
- *[r]* is a modifying parameter.

In the following the foundations of GST will be provided, beginning with a traditional GM(1.1), continuing with the description of MGM(1,n) model, which is applied in this paper.

3.1 GM(1.1) Prediction Model

A Grey Model is created by an algorithmic sequence of calculations steps. Those will be presented in the following:

1. Create Raw Data Sequence:

Create a raw data sequence *y(0)* with at least four positive parameters of the relevant times series to be predicted, in the way of:

$$y^{(0)} = \{y^{(0)}(1), y^{(0)}(2), \ldots, y^{(0)}(n)\} \geq 0; n \geq 4 \quad (1)$$

2. Perform 1-AGO operation:

Calculation of new data sequence *y(1)* on the basis of *y(0)* by 1-AGO Operation (first-level accumulating generating operation), in the way of:

$$y^{(1)}(k) = \sum_{i=1}^{k} y^{(0)}(i); k = 1,2,\ldots,n \quad (2)$$

With every iterative step the previous data sequence *y(0)* will be replaced by a new data series *y(1)* with *y(1)(n+1)* data parameters.

3. Create Background sequence by 1-MGO:

Calculation of a background sequence z(1) on the basis of y(1) by 1-MGO Operation (first-level mean generating operation), in the way of: