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Time-clustering behavior and cycles in the time dynamics of car accident sequences in Lebanon

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HIGHLIGHTS

- Temporal properties of car accidents in selected Lebanese cities were analyzed.
- One-day cycles characterize the whole Lebanese dataset.
- Significant scaling behavior characterize the whole Lebanese and Greater Beirut dataset.
- Cycles of increasing period feature cities with increasing distance from Beirut.

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ABSTRACT

This manuscript analyzes the temporal properties of sequences of car accidents in Lebanon from 2015 to 2018, using data from the Lebanese Road Accident Platform (LRAP). The Allan Factor that is a well suited methodology for investigating the time-clustering in point processes, revealed that the car accidents occurred over the whole Lebanese territory are characterized by a significant scaling behavior for timescales larger than about 2 weeks, with a clear cyclic component at 1 day. The analysis performed on car accident sequences in some specific areas of Lebanon revealed the presence of cycles varying from 1 day to 2 weeks as a function of the distance from Beirut, the capital city of Lebanon.

1. Introduction

Urban areas nowadays account for more than half of the world's population where traffic accidents constitute the most frequent cause of death among the 15–29 age group [1]. Car crashes injuries are predicted to become the third leading global cause of disease and injury by 2020 [2].

In accordance with the Global Plan of the UN Decade of Action for Road Safety (2011–2020) [3], UN Sustainable Development Goals (SDG) aspires to make cities safe and reduce by halve the cumulative number of casualties from car crashes by the year 2020 [4].

Brasilia Declaration on Road Safety [5] recommended to promote safety and resilience of cities and improve data collection on the occurrence of road traffic crashes in order to provide policymakers with intelligent data about accidents' hazard that can be used to analyze and assess national road conditions and predict crashes occurrence given the involved agents and parameters. This requires data collection with a fine-grained precision, data categorization, and then the utilization of appropriate tools to identify patterns and continuously refine the model as real time data is being gathered.

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Several developed countries were successful in reducing the number of traffic accidents such as Sweden who adopted a "Vision Zero" plan, with the goal to reduce to zero road traffic casualties. However, in Lebanon, traffic accidents are calculated to account for more than 1.5% of the national economy GDP [2]. Lebanon suffers a high road death rate with nearly 15 deaths per 100,000 people. In an effort to alleviate this burden, a new Lebanese's traffic law (Law number 243) became effective in April 2015.

Due to the lack of statutory authority in charge of collecting and reporting accidents' related data in Lebanon, the Lebanese Road Accident Platform (LRAP) was proposed in [6] as an online crash occurrence data warehouse publicly available since 2015 on near real-time to policy makers, various stakeholders and researchers in the field. LRAP serves several long term objectives to help the authorities in laying down the appropriate measures for traffic accidents prevention.

2. Methodology

A sequence of car accidents can be considered a point process in time. As for many other temporal point processes, the Allan Factor method is well suited to carry on the investigation of its properties, like time-clustering behavior or correlation structures. The representation of such sequence can make use of a finite sum of Dirac's delta functions centered on the time t_i of the occurrence of the car accident:

$$y(t) = \sum_{i=1}^{N} \delta(t - t_i) \tag{1}$$

where N is the length of the sequence.

Considering the timescale τ, the whole investigation period can be divided into contiguous counting windows with the same duration τ; thus, a discrete non-negative series of counts $\{N_k(\tau)\}$ can be formed, where $N_k(\tau)$ indicates how many events fall in the kth window [7]:

$$N_k(\tau) = \int_{t_{k-1}}^{t_k} \sum_{j=1}^{n} \delta(t - t_j)dt \tag{2}$$

Such counting process representation preserves the link between the discrete time axis of $\{N_k\}$ and "real" time axis of the original point process, allowing the correlation found in $\{N_k\}$ to be linked with that in the original point process [8]. The definition of the Allan Factor (AF) is the given by the following formula

$$AF(\tau) = \frac{\langle (N_{k+1}(\tau) - N_k(\tau))^2 \rangle}{2\langle N_k(\tau) \rangle} \tag{3}$$

Which depends on the variance of the counting process [9].

For a homogeneously Poissonian process, the AF is almost flat for any timescale range, while any deviation from this behavior indicates that the temporal distribution of the events is clusterized. In case of fractal behavior, a power-law relationship with the timescale τ characterizes the AF:

$$AF(\tau) = 1 + \left(\frac{\tau}{\tau_1}\right)^{\alpha} \tag{4}$$

with the power-law exponent $\alpha > 0$ quantifying the "strength" of the time-clustering; τ_1, known as fractal onset time, represents the inferior timescale above which significant fractal behavior can be detected in the AF; thus in the timescale range $\tau \ll \tau_1$ clustering is negligible [10]. The value $\alpha = 0$ depicts Poissonian point processes (characterized by independence and absence of memory phenomena), whose AF is rather flat at any timescale.

3. Results

We applied the Allan factor to the whole Lebanese car accident database from 2015 to 2018, and to some sub-sequences extracted from it, corresponding to the Greater Beirut Area, Beirut City, Khaldeh (Southern Beirut Entrance), in addition to two coastal cities (Saida and Tyre).

Fig. 1 shows the hourly accident distribution for different days of the week. A peak at 14:00 is visible on Monday that is the first day of the week, in which enormous traffic jam takes place due to schools and universities dismissal time and employees starting to leave work. Another peak is shown on Sunday afternoon, when generally people travel back home after spending the weekend in the mountains.

Fig. 2 shows the AF curve calculated for the whole Lebanese car accident series (black circles) and its smoothed curve (blue).

In order to evaluate the significance of the results, we applied the surrogate analysis, computing the AF for 1000 surrogate sequences obtained randomly shuffling the interevent times of the original sequence; in this manner surrogates, although preserving the same distribution of the interevent times of the original sequence, are characterized by a random behavior, since all the inner correlations are destroyed by the shuffling. At each timescale, then, we calculated the 2.5th and 97.5th

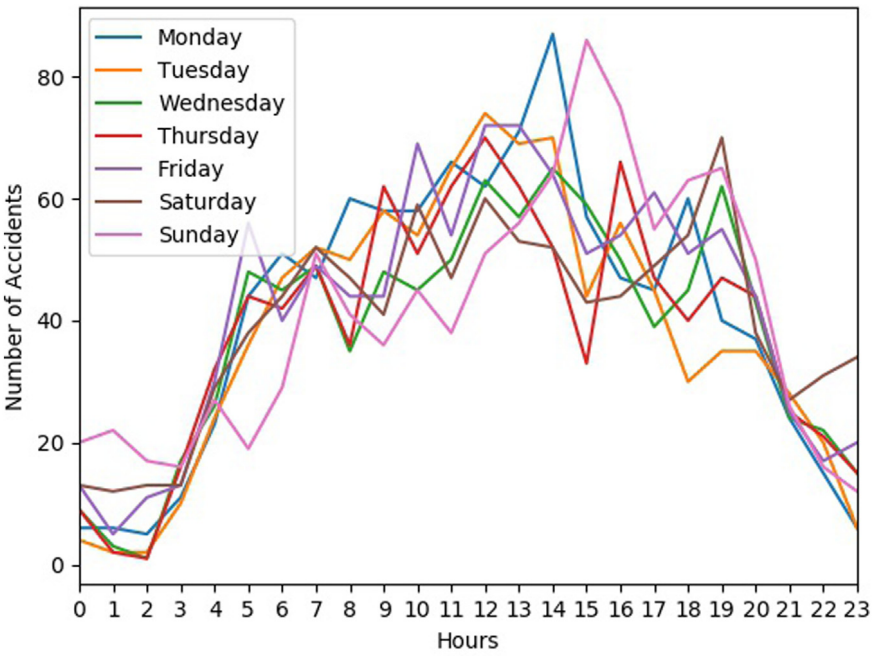

Fig. 1. Accidents distribution over time for different days of the week.

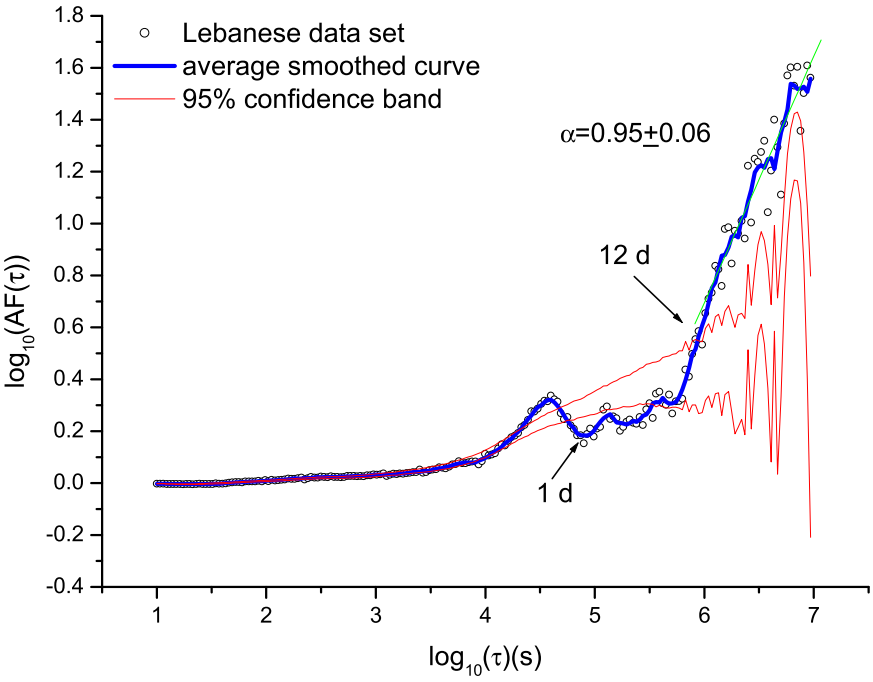

Fig. 2. Allan Factor of the Lebanese car accident sequence from 2015 to 2018.

percentiles of the AF values of the surrogates, enveloped all the percentiles, and obtained the two curves (red) delimiting the 95% confidence band. If the AF of the original series is within the 95% confidence band, it means that the series has no time properties substantially distinguishable from those of the surrogates, so, its behavior is random. Otherwise, if the AF of the original series is beyond the 95% confidence band, it means that the series is significantly not random.

From the AF of the original series, several features can be deduced:

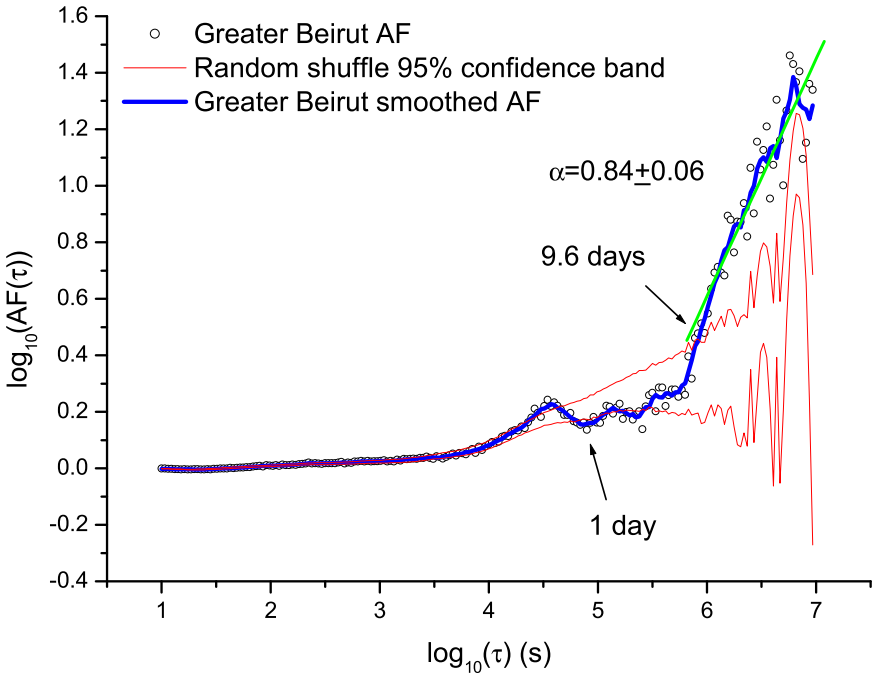

Fig. 3. Allan Factor of the Greater Beirut area car accident sequence from 2015 to 2018.

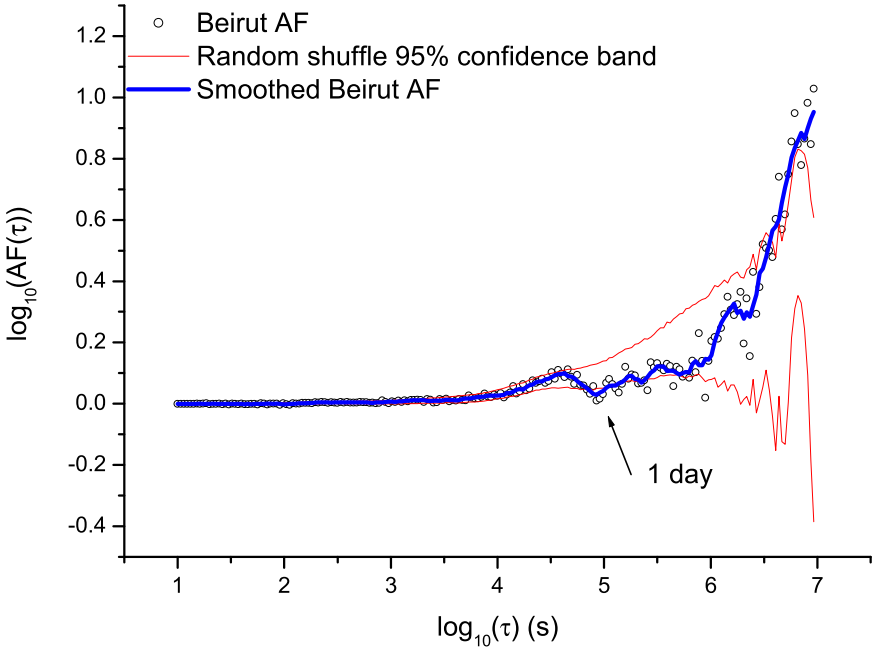

Fig. 4. Allan Factor of Beirut city car accident sequence from 2015 to 2018.

(i) The strongly irregular shape of the AF, which is not flat at all the observed timescales, indicates that the car accident series is not homogeneously Poissonian; in fact the AF curve is approximately flat until about 10^4 s, then for larger timescales it is characterized by a certain oscillatory behavior followed by an approximately linear increase in log–log scales.

(ii) A periodicity of about 1 day is revealed by the drop in the AF curve at the same timescale. Being above the 95% confidence band, such periodicity is significant and could be explained with the diurnal cycle of vehicular traffic flow and rush hours, which repeat on a daily basis and is highly correlated with the occurrence of car accidents.

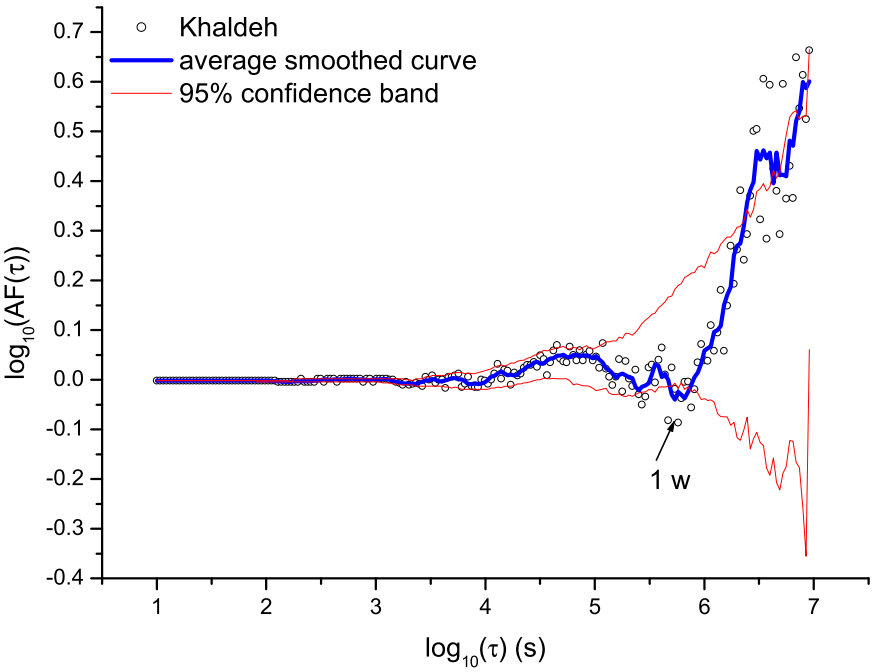

Fig. 5. Allan Factor of Khaldeh (Southern Beirut Entrance) car accident sequence from 2015 to 2018.

(iii) The AF power-law exponent is about 0.95, suggesting the existence of rather intense time-clustering in the car accidents from a timescale of about 12 days that seems consistent with the 13.5 day oscillatory behavior of several solar parameters, like solar wind, solar emissions, sunspot area, etc. [11]. Actually, the occurrence of car accidents has been put in relationship with cosmic or geophysical activity, or with sun spot frequencies [12]. Interestingly, the timescale of about 2 weeks was also observed in similar paper by Telesca et al. [13] where the car accident series occurred in USA were analyzed. Such strong similarity could suggest a sort of universal behavior in the car accident times series.

(iv) Fig. 3 shows the AF (black circles-original, blue curve-smoothed) of the Greater Beirut Area, in addition to the surrogate analysis which showed the 95% confidence band (red curves). A clear cyclic component at 1 day is observed. For the Greater Beirut Area, also a power-law behavior for a period of two weeks starts from the timescale of approximately 9.6 days, with scaling behavior of about 0.84, a little less than that found for whole Lebanon.

(v) Figs. 4 to 7 show the AF for Beirut, Khaldeh, Saida and Tyre, respectively. For all these cities, the time distribution of the car accidents does not show significant time-clustering behavior, since the AF curve is nearly embedded within the 95% confidence band. However, it is striking the appearance of the cycle, whose period grows as the distance from the capital Beirut. In Beirut, the periodicity is 1 day, whereas in Khaldeh (the Southern Beirut entrance) the periodicity is about 1 week (Fig. 5). In Khaldeh, huge traffic builds up in peak hours during weekdays, while no major traffic is detected during the weekend. The same applies for Saida (Fig. 6), a coastal city 40 km away from Beirut: Saida is a compulsory corridor for the citizens of Nabatiyeh and South Lebanon governorates, who commute daily to the capital. In Tyre, a coastal city which is 82 km away from Beirut, the periodicity is found to be about 2 weeks (Fig. 7). Transportation cost to Tyre is relatively expensive due to the absence of any sort of public transportation; and thus, many citizens prefer to live in Beirut and visit Tyre biweekly, usually once at the beginning of the month, when salaries are received, and towards the middle of the month. Moreover, Tyre is not a governorate center (like Saida) and thus no major institutions that offer public services are found there (citizens and public employees do not have to commute to the city).

4. Conclusions

We performed a detailed analysis of the temporal properties of the car accident sequence that was recorded in Lebanon from 2015 to 2018. We analyzed the car accidents occurred in whole Lebanon and in selected cities, with different distance from the capital Beirut. Time-clustering structures, indicating that the events are not independent, uncorrelated and not Poissonian were found in the whole Lebanese and in the Greater Beirut area, while no significant scaling behavior was identified in the other datasets. However, all the datasets are characterized by significant periodicities ranging from 1 day

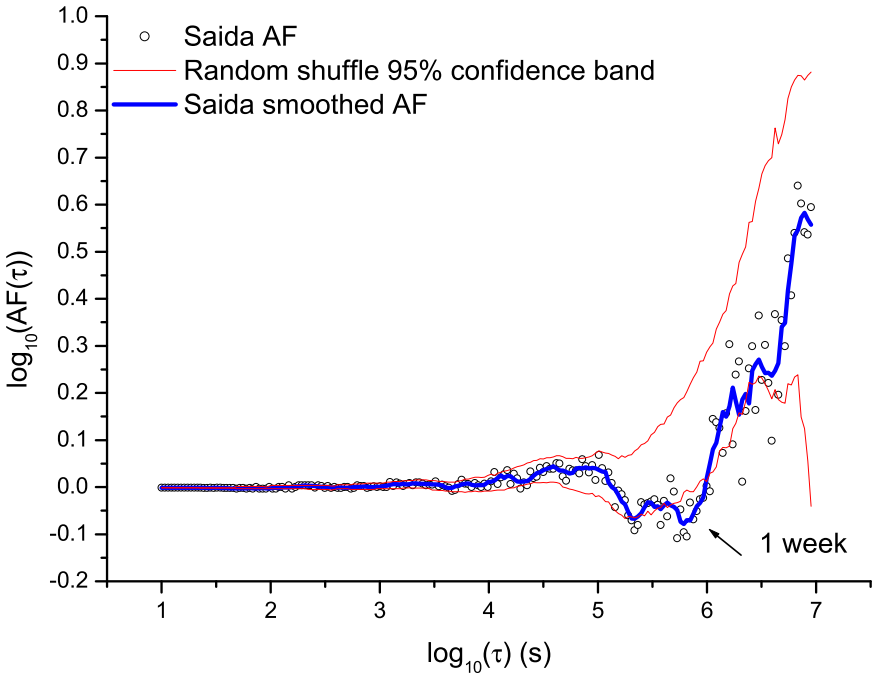

Fig. 6. Allan Factor of Saida (Sidon) city car accident sequence from 2015 to 2018.

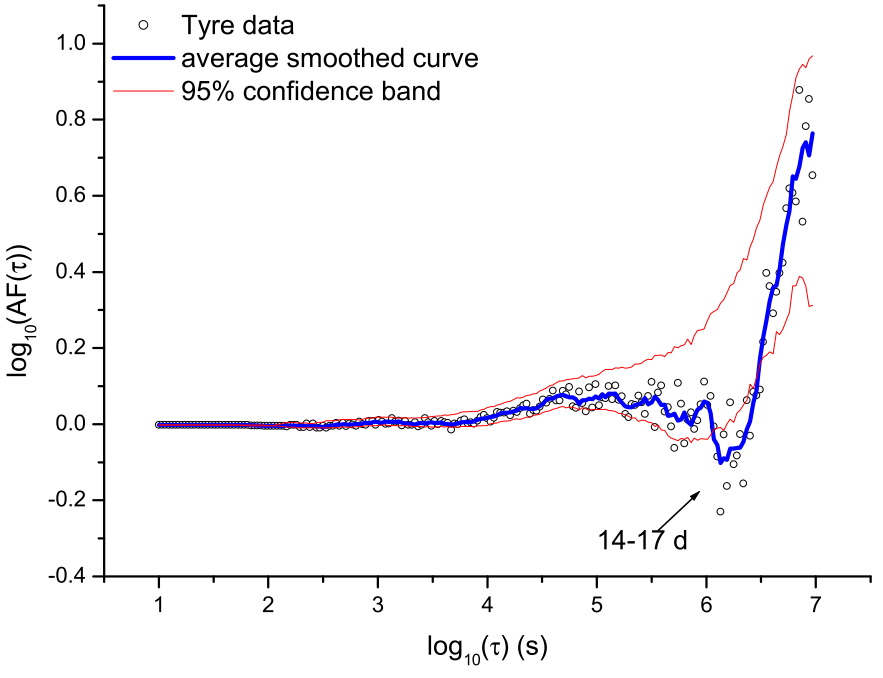

Fig. 7. Allan Factor of Tyre car accident sequence from 2015 to 2018.

to 2 weeks, nearly depending on the distance from the capital Beirut. These results will contribute to a better understanding of the space–time dynamics underlying traffic crashes processes.

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