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Original scientific paper

Impact of cyclic external factor of Moon phases on the risk of Railway Accidents occurrence

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Abstract

The impact of three external cycle factors has been research on the sample of 3983 railway accidents from 2006 to 2012 at *Serbian Railways*. Year cycle, the cycle of Moon phases and day cycle have been verified as significant factors for the risk of railway accidents. Differentiation between the factors is performed precisely. The Moon phases have particularly significant impact on the frequency of railway accidents. Quite opposite to the traditional approach, which puts an accent on the negative impact of the Full Moon phase, the analysis in this paper emphasizes a complementary result – the positive impact of the Young Moon phase, as well as big spans in RA frequencies according to Moon phases, which are particularly significant.

Keywords: moon, railway, accidents, risk, traffic.

Introduction

One of the fundamental goals of every railway management is to increase the safety of railway traffic by reducing the number of railway accidents. Former analyses point out the tendency of decrease in the number of railway accidents (Evans, 2011; Silla and Kallberg, 2012).
Due to specific conditions of traffic, there is a specified group of factors in railway traffic, which are applied in estimating a risk and predictability of occurrence of an accident (Evans, 2003). This specific task is completed by complex models (Oha et al., 2008; Mirabadi and Sharifian, 2010; Ouyang et al., 2010; Underwood and Waterson, 2013), which may provide good results in regard to estimating the number of railway accidents. Nowadays good estimate results emphasize critical and the most frequent accidents, to which preventive measures are applied: introduction of improved signaling systems (Evans and Verlander, 1996), education of schoolchildren (Lobb et al., 2003), training of pedestrians (Lobb et al., 2001), introduction of active signaling systems at level crossings (Teya et al., 2011) and many others. Much attention is paid to human factor as one of the commonest causes of accidents ***- 70% of accidents occur due to the attention deficit of train drivers (***Edkins and Pollock, 1997). The factors that influence the attention of train drivers Several factors that influence the attention deficit of train drivers and proceeding at the stop signal have been considered, including (reaction time of train driver), interaction with commands and the limited distance of signal visibility. It has been concluded that these factors have a large impact on the attention deficit of train drivers (Naweed, 2013). However, the role of human factor in accidents should not be limited to train drivers only, with respect to the large

number of staff that participates in the railway traffic operation and control. Almost all accidents are connected to the organizational factor (Baysari et al., 2008), i.e. to the problems in the organizing process, management, or even to the company “climate”. As much as 30% of accidents occur due to the bad “attitude“of personnel, which is reflected by low work ethic, lack of pride, low motivation, performing tasks without following the procedures, etc. (Edkins and Pollock, 1997).

Space and time perception of approaching railway vehicles by road users at level crossings, also has a significant impact on occurrence of accidents, since road users cannot estimate good at estimating the speed of an approaching vehicle well if it is of large dimensions, as in the case of trains (Clark et al., 2013).

Privatization of numerous railways imposed the question of safety, as regards the change of ownership structure. Results of some researches show that privatization does not lead to regression of traffic safety as in the cases of the railway systems of Great Britain (Evans, 2007) and Japan (Evans, 2010). This issue is also rather significant for *Serbian Railways*, which are undergoing a major restructuring.

All above-mentioned researches of accidents are focused on human factor, railway staff, users of railway services and individuals that cross the territory of railways. However, there are not many analyses of factors that may indirectly influence human behavior at the occurrence of accident. These factors are considered external and their impact is the most prominent through meteorological conditions, primarily reduced visibility (rain, fog, and snow), impact of extreme temperatures on motor and perceptive abilities of railway workers. These external factors have scientifically grounded physiological impacts, and a large number of procedures is adjusted to these disorders.

One of the external factors that has not been researched so far is the impact of Moon phases on occurrence of railway accidents. It is assumed that this impact may be realized indirectly through the changes in human behavior. Number of papers about this subject provides a solid ground that justifies this kind of research. If it is intended to improve safety, every approach is allowed and every result, regardless of its positive, particular or negative conclusions, is significant.

Facts about the Moon

The Sun and the Moon are the most important astronomical objects. All life on the Earth and time measurement exist in cycles determined by the Sun and the Moon.

The Moon is an astronomical object closest to the Earth, a natural satellite that revolves around Earth in an *elliptical orbit.* The Moon orbit the Earth at an average distance of 384.403 km. The distance at the perigee is 362 570 km and distance at the apogee is 405 410 km. The diameter of the Moon is 3473.3 km and its mass is 80 times smaller than that of the Earth. Average speed of the Moon around the Earth is 1.02 km/sec, and it angular speed is 13°10′/day. Inclination of orbit to ecliptic is in the range of ± 5°18′ within the cycle of 173 days. The moon rotates around its axis for 27 days, 7 hours and 11.5 seconds (sidereal month), synchronous towards the Earth.

Due to the constant changing of position towards the Sun and the Earth, the intensity of light on the Moon varies. Figure 1 shows the four phases of the light intensity:

1. Young Moon, phase I, in which the shadowed portion is facing the Earth, the Moon is invisible, except during an eclipse of the Sun
2. First Quarter, phase II, in which the disc on the right side is partially lit, the Moon is visible in the evening and it sets at midnight
3. Full Moon, phase III, in which the disc is completely illuminated, the Moon is visible throughout the night
4. Third Quarter, phase IV, in which the disc on the left side is partially lit, the Moon rises at midnight and is visible until sunrise.

The period of the Moon's phases is the synodic month and it lasts 29 days, 12 hours, 44 minutes and 3 seconds.

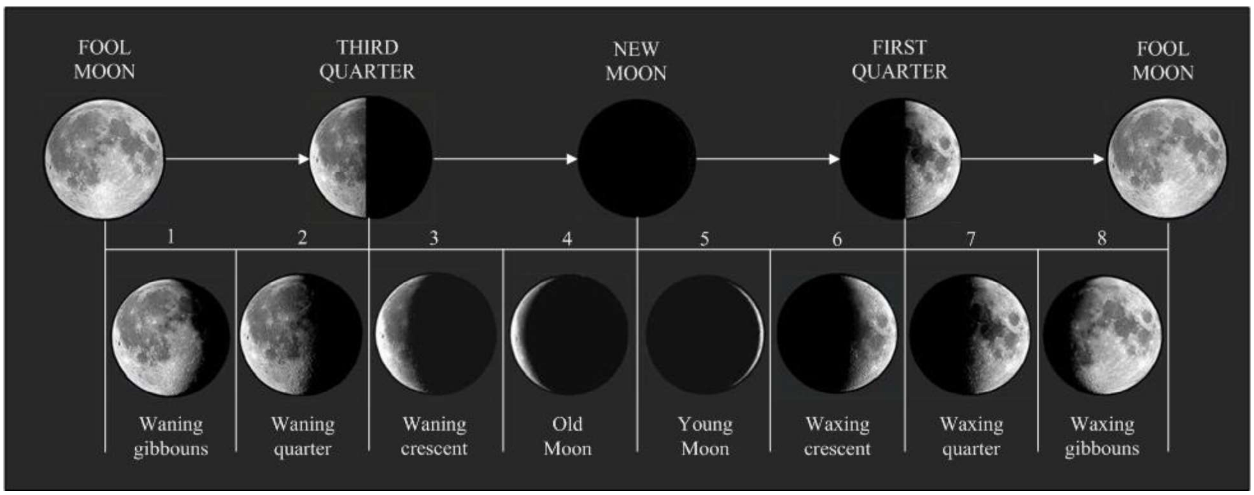


Figure 1. Moon phases split on 8 parts. 1-Waning gibbous, 2- Waning quarter, 3- Waning crescent, 4- Old Moon, 5- Young Moon, 6- Waxing crescent, 7- Waxing quarter, 8- Waxing gibbous

Gravitational impact of the Moon to the Earth

The clearest impact of the lunar and solar potential on the Earth is the tide. Three basic astronomical movements control the tidal pulses within the Earth-Moon-Sun rotational system. The observed tidal pattern occurring at a particular point on the Earth's surface is the sum of a number of harmonic components associated with lunar and solar astronomical cycles (Brown et al., 1989; Martino and Sanderson, 1993). Tide's harmonic analyses are represented with diurnal, semidiurnal and mixed types systems (Mazumder and Arima, 2005) and tidal resonance (Zhong et al., 2008).

Tidal attractions, exerted by the Moon and the Sun, also induce elastic deformation of the solid Earth (Metivier et al., 2009) as well as the changes in gravitation (Latychev et al., 2009). The concept of the earthquake tidal triggering is more than 110 years old (Knopoff, 1964, Emter, 1997). Since the early analyses on impact of the Moon (Tamrazyan, 1967) and the Sun (Tamrazyan 1968), several studies have reported small positive correlations between the Earth core tide and earthquake occurrence (Tanaka et al., 2002; Cochran et al., 2004), but typically only for a particular geographic region (Souriau et al., 1982; Wilcock, 2001; Tolstoy et al., 2002; Kasahara, 2002).

However, there are also studies with significant correlation between earthquakes and solid-earth tides, established for the intervals of solar declination, time of day, lunar declination and lunar phase (Weems and Perry, 1989). Furthermore, the occurrence of times of moonquakes showed tidal periodicities (Minshull and Goulty, 1988). It has been established that there is a correlation between considerable seismic activities on the Earth and Moon (James, 1986) and temporal correlation between shallow moonquakes and large shallow earthquakes (Shirley, 1986). Moonquake nests are mainly on the near side of the Moon (Frohlich and Nakamura, 2009). This fact is particularly significant because of synchronic movement of the Moon.

Impact of lunar phases on human behaviour

There have been many papers so far that research the correlation between lunar phases and human behavior. In most of them the full-moon phase is given obvious numerical prevalence, while the number of researched cases does not provide significant statistical difference. Therefore, further research of the correlation between lunar phases and researched phenomena is terminated. Most of these research papers deny the mythological ground, but also state that the methodology used for research might not have been the best possible.

On the other hand, it was found that the frequency of calls to emergency services (Bickis et al., 1995; Wolbank et al., 2003)***, crisis centers (***Wilson and Tobacyk, 2001***), police and fire departments (***Frey et al., 1979***) points out the impact of Moon phases. However, the authors failed to present the relevant factors statistically. The low impact of lunar phases on crime (***Schafer et al., 2010), particularly by the higher number of burglaries, was explained by favourable conditions in the young-moon phase due to the reduced night luminescence.

In the animal world lunar phases have explicit impact on the intensity of predatory activities (Penteriani and Kuparinen, 2011), number of animal bites during the full-moon phase (Bhattacharjee et al., 2000) and aggressive behaviour of animals in general (Biermann et al., 2005). It correlates with the increasing intensity of violence and aggression of people during the full-moon phase (Owen et al., 1998).

A significant impact of Moon phases has been confirmed for many psychopathic disorders: the rate of suicide attempts and committed suicides (Biermann et al., 2005; Eisenbach et al., 2008; Voracek et al., 2008), psychiatric admissions (Kazemi-Bajestani et al., 2011), madness (Raison et al., 1999), trauma (Stomp and Nijstenc, 2011), panic attacks in women during Full Moon phase (Bulbena et al., 2004), unexplained stroke symptoms (Ahmad et al, 2008), unintentional poisoning (Oderda and Klein-Schwartz, 1983; Amaddeo et al., 2000), disproportionately larger number of sudden unexpected death in epilepsy (SUDEP) (Terra-Bustamante et al., 2009), epileptic seizures (Baxendale and Fisher, 2008; Polychronopoulos et al., 2008) and non-epileptic seizures (Benbadis et al., 2004), etc.

Mythology about the impact of Full Moon is most probably based on the correlation of Moon phases and attacks caused by psychopathic disorders. Correlation with Moon phases has been established, but the scientific study has not yet pointed out both the cause factors and their effects. Within the scope of normal physiology, the only significant impact of Moon phases (Full Moon) that has been confirmed is the one that affects duration of sleep (Roosli et al., 2006; Cajochen et al., 2013) and growing intensity of night luminescence has been identified as a cause.

Besides numerous differences, authors agree that every problem should be approached individually and that it is important to choose the right methodology, since the impact of the

Moon can be considered depending on its phase, distance, the intensity of light it gives off, meteorological conditions, season, etc. This wide definition of Moon's impact on numerous phenomena implies that further research in all fields of science is required.

Collected Data and Analysis

The total number of accidents that occurred on the territory of *Serbian Railways* between 2006 and 2012 was 3939, as shown in Figure 2. The database about railway accidents at Serbian Railways includes the following items: date and time of the railway accident, type and cause of the railway accident, a brief description of the railway accident, records of fatalities and injured passengers, railway workers or other individuals, duration of traffic break after an accident, data about the material damage after an accident, person responsible for occurrence of an accident.
Analysis of accidents that occurred at *Serbian Railways* is performed at least once a year. It should include some characteristic examples of accidents that had occurred.
The term accident and its structure are not defined in the same way at all railways. This is particularly the case with the structure of accident, which makes a comparison of railways somewhat difficult. At some railways avoided collisions and avoided crashes are considered to be accidents, while at others they are regarded as disturbances to the traffic or, for example, some railways consider only collisions of trains as collisions, while other include all kinds of crashes hits into other trains, shunting vehicles, railway or road vehicles at level crossings, hits into land-slides, i.e. hits to any kind of obstacle.
The shortcoming of traditional approach is the fact that the same number of accidents or their similar structures do not necessarily mean that the railway safety performances are at same levels, if different scopes and structures of traffic are taken into account. In the cases of accidents, therefore, relative indicators of railway safety are now considered. They include some traditional absolute indicators, which are narrowed down to appropriate indicators of work scope (Table 1).

Table 1. Basic indicators of work scope

	PASSENGER TRAFFIC		FREIGHT TRAFFIC		
Year	Number of passengers (thousand)	Passenger kilometers (million)	Loading (thousand)	Unloading (thousand)	Net -ton kilometers (million)
2006	14.084	874	5.860	5.992	3.857
2007	9.794	762	5.727	6.061	4.107
2008	8.854	648	5.109	5.569	3.967
2009	8.384	590	4.125	4.641	2.739
2010	6.721	516	5.863	5.590	3.265
2011	9.376	589	5.755	5.775	3.316
2012	16.626	700	3.747	4.107	2.498

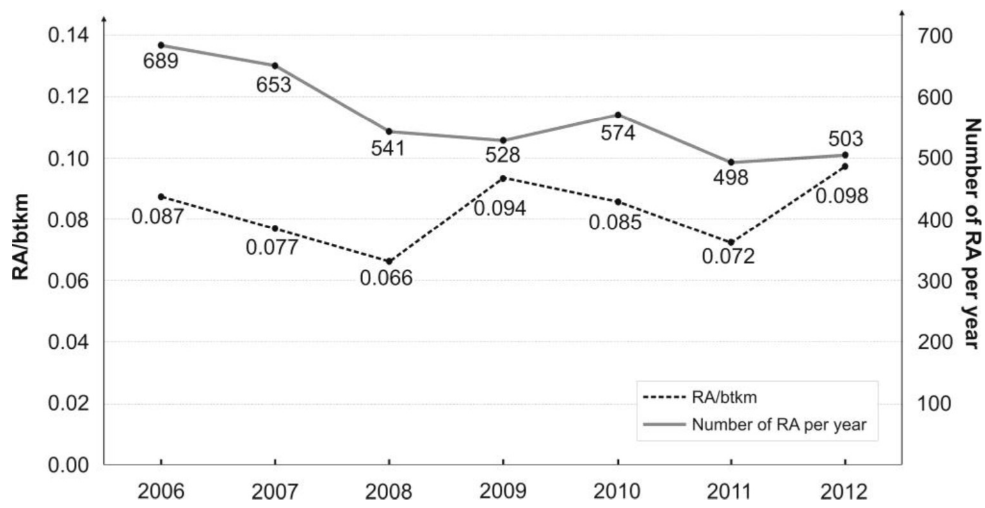


Figure 2. RA per brkm and yuear

From 2006 to 2012 a trend of slight increase in number of railway accidents per gross-ton kilometer was confirmed. A mean number of accidents per day is 1,556556, with standard deviation of 0.531263. While searching for the best description, Normal, Weibull and Log-normal distributions had a satisfactory significance (p>0,05). The biggest significance was achieved by Gamma distribution (p=0.1135>0.05) with the scale parameter of 5.245383 and the shape parameter 8.1647329. Fig. 3 shows the verification of non-parameter hypothesis of Gamma distribution of railway accidents.

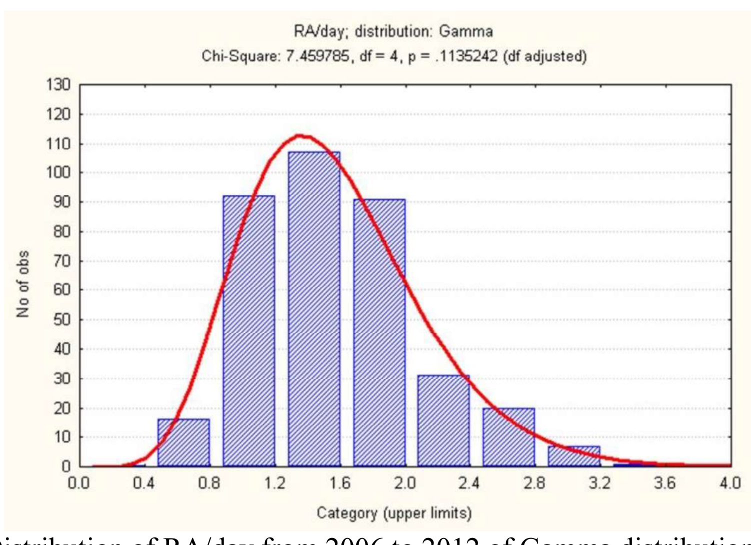


Figure 3. Distribution of RA/day from 2006 to 2012 of Gamma distribution verification

In addition to the common internal factors, existence of the following cyclic external factors is assumed: year cycle, the cycle of Moon phases and day cycle.

The frequency of railway accidents in the year cycle is organized according to dates, and then approximately according to decades (36 classes). A series of the lowest frequencies was confirmed for the decade from 102nd to 112th day of a year, which corresponds to the second decade of April, while the highest is confirmed from 193rd to 203rd day of a year, which corresponds to the second decade of July. Distribution of railway accidents at Serbian Railways in the year cycle is not even. Verification of non-parameter of hypothesis of even distribution in the year cycle results in χ^2 value of 83.90717, which for 34 degrees of freedom gives the significance threshold of p=0.0000043. The existence of year cycle factor is obtained with extremely high significance (Figure 4).

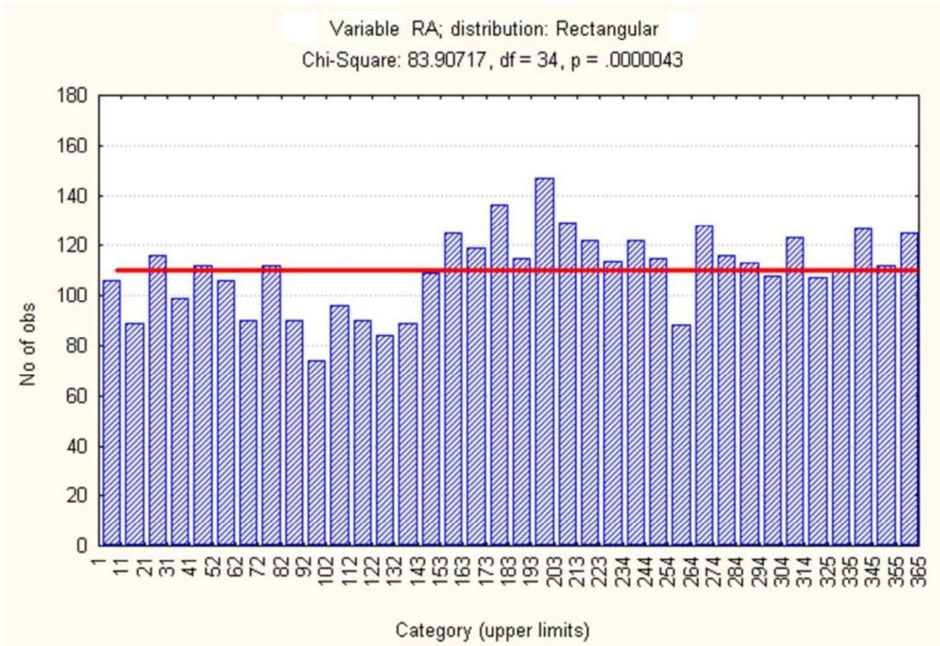


Figure 4. RA distribution in the year cycle from 2006 to 2012

Frequencies of RA in the cycle of Moon phases are organized into 8 classes: Waxing gibbous (8) and Waning gibbous (1), Third quarter is decomposed into Waning quarter (2) and Waning crescent (3), New moon is decomposed into Old moon (4) and Young moon (5), while First quarter is decomposed into Waxing crescent (6) and Waxing quarter (7). The lowest frequencies are confirmed in the Young moon phase (5), while the highest frequencies are confirmed in the Waxing gibbous phase (8). RA distribution at Serbian Railways in Moon cycles is not even. Verification of non-parameter of hypothesis of even distribution in Moon cycles results in χ^2 value of 13.358, which for 6 degrees of freedom gives the significance threshold of p=0.0377104. Thus a significant existence of Moon cycle factor for occurrence of RA is obtained (Figure 5).

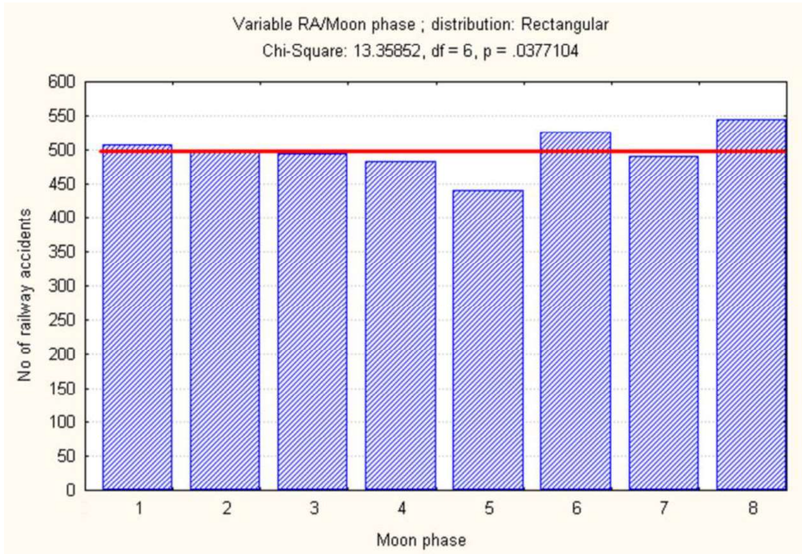


Figure 5. RA distribution according to Moon phases from 2006 to 2012

RA frequencies in the day cycle are organized in 24 classes (according to hours). The lowest frequencies are confirmed for early morning (3 a.m.), while the highest frequency is confirmed for the late afternoon (3 p.m.). RA distribution at Serbian Railways in the day cycle is not even. Verification of non-parameter of hypothesis of even distribution in the day cycle results in χ^2 value of 161.154, which for 22 degrees of freedom gives the significance threshold of p=0.00000. The existence of day cycle factor is obtained with extremely high significance.

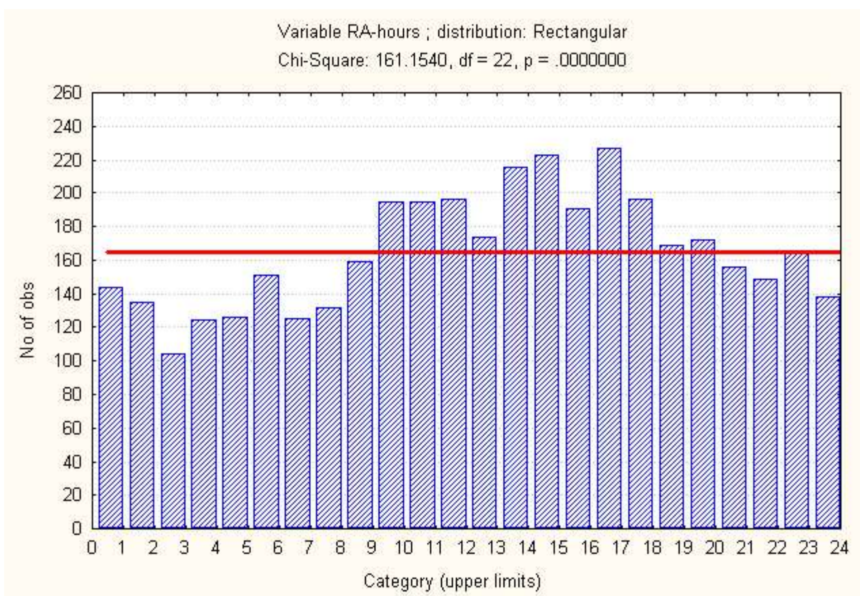


Figure 6. RA distribution during a day from 2006 to 2012

Previous statistical analysis confirms significant impacts of three external factors: Year cycle, Cycle of Moon phases and Day cycle.

Year cycle and day cycle are external factors of extremely high significance (p<0.00001), and the cycle of Moon phases is a significant external factor (p=0.0377104<0.05).

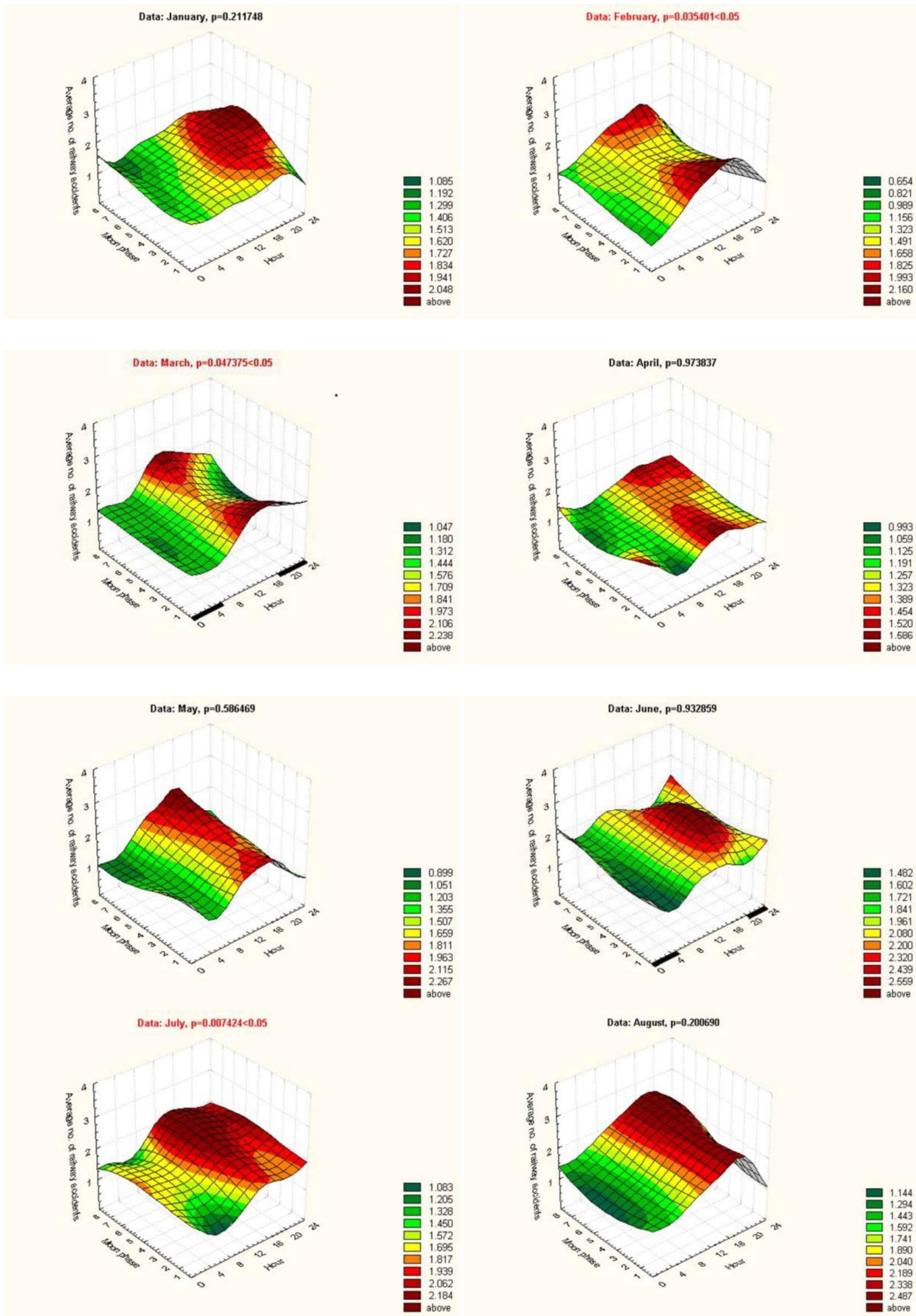
In relation to the four basic Moon phases, a year period is divided into calendar months and the analysis of variance of RA mean number according to Moon phase factor was carried out. With the significance threshold of p=0.05, it is confirmed that Moon phases are a significant factor of RA frequency in the following months: February (p=0.035401), March (p=0.047375), July (p=0.007424) and September (p=0.046268). (Table 2)

Table 2. Analysis of variance of Moon phases' impact on the mean number of RA per day for calendar months

	○ (8+1)	☾ (2+3)	● (4+5)	☽ (6+7)	p
January	$1.333\pm0.952_{min}$	1.791 ± 1.219^{max}	1.729 ± 1.215	1.750 ± 1.391	0.211784
February	1.625 ± 1.408	2.041 ± 1.570^{max}	$1.312\pm1.355_{min}$	1.333 ± 1.154	0.035401
March	1.666 ± 1.277	1.916 ± 1.426^{max}	$1.208\pm1.202_{min}$	1.375 ± 1.378	0.047375
April	1.375 ± 1.084	$1.314\pm1.132_{min}$	1.333 ± 1.136	1.416 ± 1.334^{max}	0.973837
May	1.729 ± 1.672^{max}	1.416 ± 1.268	$1.354\pm1.175_{min}$	1.458 ± 1.529	0.586469
June	1.916 ± 1.182	$1.833\pm1.373_{min}$	2.020 ± 1.604^{max}	1.958 ± 1.529	0.932859
July	2.500 ± 1.786^{max}	$1.583\pm1.318_{min}$	1.833 ± 1.4041	2.458 ± 1.923	0.007424
August	2.062 ± 1.435	1.979 ± 1.550	$1.541\pm1.184_{min}$	2.083 ± 1.441^{max}	0.200690
September	2.083 ± 1.268^{max}	1.562 ± 1.029	$1.479\pm1.458_{min}$	1.480 ± 1.091	0.046268
October	1.916 ± 1.513	$1.583\pm1.251_{min}$	1.979 ± 1.344^{max}	1.854 ± 1.336	0.504961
November	1.812 ± 1.393	$1.541\pm1.237_{min}$	1.770 ± 1.340	1.958 ± 1.336^{max}	0.489225
December	1.833 ± 1.492	2.145 ± 1.414^{max}	$1.687\pm1.370_{min}$	2.041 ± 1.304	0.374903

The maximum mean number of RA according to months is evenly distributed as followed: 3 maxima in the Full Moon phase, 4 maxima in the Third Quarter phase, 2 maxima in the New Moon phase and 3 maxima in the First Quarter phase. Minima are distributed unevenly: 1 minimum in the Full Moon phase, 5 minima in the Third Quarter phase, 6 minima in the New Moon phase and 0 minimum in the First Quarter phase.

In order the get a clearer perspective of the year cycle, Moon phases cycles and day cycles, a graph of two-dimensional functional dependence of mean number of RA per day was made for each calendar month (Figure 7). Independent random variables are the cycle of Moon phases and day cycle. At the axis of day cycles, duration of day and night is emphasized at spring and autumn equinoxes (21 March – the beginning of spring, 22 September – the beginning of autumn), at winter solstice (22 December – the beginning of winter) and summer solstice (21 June – the beginning of summer). The variable of year cycle is contained in differentiation between calendar months and thus the characteristics of certain periods of the year cycle have been selected, primarily average temperature, cloud cover, humidity, air pressure, etc.


Data: January, p=0.211748
Average no. of railway accidents
Moon phase
Hour
1.085
1.192
1.299
1.406
1.513
1.620
1.727
1.834
1.941
2.048
above
Data: February, p=0.035401<0.05
0.654
0.821
0.989
1.156
1.323
1.491
1.658
1.825
1.993
2.160
above
Data: March, p=0.047375<0.05
1.047
1.180
1.312
1.444
1.576
1.709
1.841
1.973
2.106
2.238
above
Data: April, p=0.973837
0.993
1.059
1.125
1.191
1.257
1.323
1.389
1.454
1.520
1.586
above
Data: May, p=0.586469
0.899
1.051
1.203
1.355
1.507
1.659
1.811
1.963
2.115
2.267
above
Data: June, p=0.932859
1.482
1.602
1.721
1.841
1.961
2.080
2.200
2.320
2.439
2.559
above
Data: July, p=0.007424<0.05
1.083
1.205
1.328
1.450
1.572
1.695
1.817
1.939
2.062
2.184
above
Data: August, p=0.200690
1.144
1.294
1.443
1.592
1.741
1.890
2.040
2.189
2.338
2.487
above

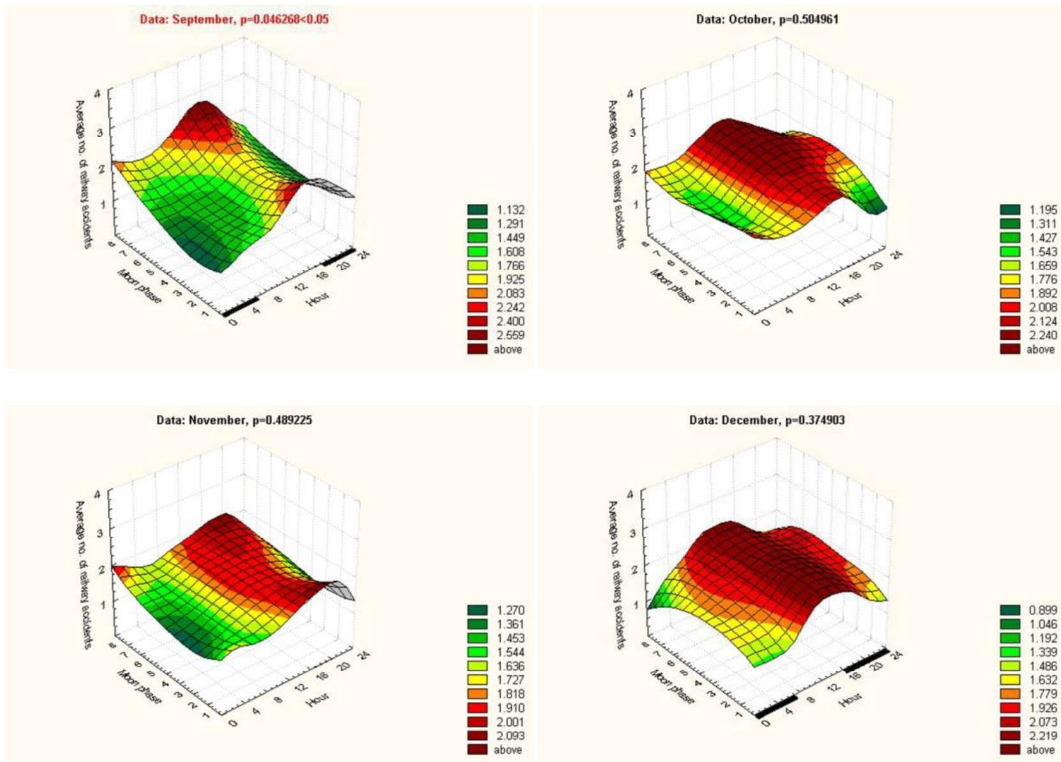


Figure 7. Two-dimensional RA distribution in the function of moon phases and part of day, differentiation according to months

The significant impacts of Moon phases in February, March and September show similar patterns. The graph saddle point with maxima in Waxing gibbous (8) and Waning gibbous (1) may be noticed from noon to 6 p.m.

The minimum of RA in February and March is noticeable in the New Moon phase. The general minimum of RA is 1.208 and it confirmed in March in the New Moon the second lowest mean value of 1.312 is confirmed in February, in the New Moon phase. This prominent unevenness is the basis of significant differences according to Moon phases, which was established by the analysis of variance.

The maximum value of 2 500 RA in the Full Moon phase was confirmed for July. This value is the general supremum. Though it is not emphasized as a maximum, the mean value of RA/day of 2.4583 is confirmed in the First Quarter phase in July and represents the second highest value of RA/day. At the territory of Serbia, the calendar month July has the highest mean air temperature. It should be emphasized that during the First Quarter phase (indicated by number 6 and 7 in the graphs) in which the disc on the right side is partially lit, the Moon is visible in the evening and it sets at midnight. High mean value of RA/day during the First Quarter and Full Moon phases continues until midnight, which is particularly characteristic for July. In other calendar months the intensity of RA/day decreases after 8 p.m.

The traditional understanding of extremely negative impact of the Full Moon has been confirmed at *Serbian Railways* for February, March, July and September.

February, March and September have the same pattern, which represents the synergy of high frequency of RA in the afternoon (biggest migrations of population). It should also be emphasized that March and September are the months of equinoxes, changes of seasons and the change of calculating time (transition from winter to summer time or vice versa).

July is the hottest month with summer solstice and small cloud cover. Maximum values of RA/day are confirmed in the First Quarter, when Moon luminescence extends from evening into the night (the Moon is visible and it sets at midnight), and in the Full Moon phase with the maximal luminescence during the night.
Despite the traditional approaches, which are based on the negative impact of the Full Moon, in December and January a small number of RA/day is noticeable in Waxing gibbous (8) and Waning gibbous (1) (Full Moon phase) during the night. December and January are the months with the shortest day lengths. If the period from 4 p.m. to 7 a.m. of the following day (night length) during these months is considered separately, the analysis of variance ($P=0,041709<0.05$) will confirm the lowest number of RA/day in the Full Moon phase, with maximal cloud cover of 70%, which is typical for Serbia at that time of the year. This means that the particular positive impact of the Full Moon has been confirmed statistically.
The largest number of minima of RA/day is confirmed in the Young Moon phase. Eleven out of twelve minima of RA/day are in the Third Quarter phase, when the moon rises at midnight and is visible in the morning and in the Young Moon phase (Table 2). The only remaining minimum is confirmed in the Full Moon phase in January, which is verified to be favorable in the cases of long nights.

Conclusion

In accordance with the numerous studies on the subject, this paper confirms the particular impact of Moon phases on frequency of railway accidents. The mechanism of Moon phases effects remains unexplained, but statistically significant impact is obvious.
The negative impact of the Full Moon has so far had the only realistic explanation in the physiology of sleep. It is proved that the quality of sleep decreases at high temperatures and high night luminescence. The synergy of these factors may directly contribute to decrease of physical abilities of individuals that participate in railway traffic and thus increase the risk of railway accidents.
The issue of choosing an approach for studying the impact of Moon phases is ambiguous and results presented in this paper do not emphasize the negative impact of the Full Moon that much, but rather emphasize the positive impact of the Young Moon. This impact is not the primary external factor, but in synergistic interaction with dominant cyclic factors, it may result in variations in frequency of railway accidents.
The range of maximal RA/day in the Full Moon phase in July (2.500) and minimal in the Young Moon phase in March (1.208) gives the quotient of 2.069, or the range of risk that is twice higher. The numerical relation is obtained from a large sample. The quotient may be largely affected by the safety context and any possibility to reduce the risk of railway accidents.
In compliance with compatible elements of the strategy for traffic safety, road traffic may serve even as a more suitable ground for researching the particular impacts of the Moon, due to the more frequent occurrence of accidents. It would be particularly valuable due to the much larger interaction among drivers in much more dynamic road traffic flows and consequently to the larger impact of human factor. The conclusion may refer to any field of work that implies certain risk.

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