A LETTERS JOURNAL EXPLORING THE FRONTIERS OF PHYSICS

LETTER

Traffic dynamics of carnival processions

To cite this article: Petros Polichronidis *et al* 2018 *EPL* **121** 68003

A Letters Journal Exploring the Frontiers of Physics

March 2018

EPL, **121** (2018) 68003 www.epljournal.org
doi: 10.1209/0295-5075/121/68003

Traffic dynamics of carnival processions

Petros Polichronidis[1(a)], Dominik Wegerle[1], Alexander Dieper[2] and Michael Schreckenberg[1]

[1] *Universität Duisburg-Essen, Physik von Transport und Verkehr - Lotharstr. 1, 47057 Duisburg, Germany*
[2] *Festkomitee des Kölner Karnevals von 1823 e.V. - Maarweg 134-136, 50825 Köln, Germany*

received 16 January 2018; accepted in final form 27 April 2018
published online 17 May 2018

PACS 89.40.-a – Transportation
PACS 05.40.-a – Fluctuation phenomena, random processes, noise, and Brownian motion

Abstract – The traffic dynamics of processions are described in this study. GPS data from participating groups in the Cologne Rose Monday processions 2014–2017 are used to analyze the kinematic characteristics. The preparation of the measured data requires an adjustment by a specially adapted algorithm for the map matching method. A higher average velocity is observed for the last participant, the Carnival Prince, than for the leading participant of the parade. Based on the results of the data analysis, for the first time a model can be established for defilading parade groups as a modified Nagel-Schreckenberg model. This model can reproduce the observed characteristics in simulations. They can be explained partly by the constantly moving vehicle driving ahead of the parade leaving the pathway and partly due to a spatial contraction of the parade during the procession.

Introduction. – The investigation of traffic dynamics has evolved to an important research field during the last decades. It is mainly concerned with the explanation and understanding of the occurrence of jams. As the traffic demand of a road exceeds the capacity, the interaction between vehicles slows the speed down and traffic jams may spontaneously occur [1]. Especially on highways jams are the main reason for time delays. Many of the phenomena are quite well understood. Traffic jams can evolve in any mode of transportation. One would usually expect that within a carnival procession, where tens of thousands of people are walking along a one-dimensional route, jam formation is also a time-consuming phenomenon. But, on the other hand, there are systems in which the opposite is true. For the first time to our knowledge, we observed shorter travel times for participants at the rear end of a procession than for those at the front. The interesting point is that looking in more detail into the dynamics of processions there are local jams, which cause no delay overall.

There is not much literature about the movement of processions. Batty *et al.*, for instance, presented a model that is intended to simulate the effects of changing the loop-like parade route in the London Notting Hill Carnival [2]. An important missing aspect relates to a realistic modeling of the kinematics of the procession itself. The underlying microscopic model takes visitors, paraders, bands and streets as agents into account. They simulate participants of a carnival procession ("paraders") with a controlled flow to give an appropriate moving behaviour in time. Furthermore an arbitrarily chosen stochastic component is introduced to incorporate the intermittency of the movement in this model. Beyond that, the paraders are uniformly distributed over amongst the total number of cells of the loop-like pathway.

Usually the route of a procession has a start and a finish and is not loop-like like the pathway in the London Notting Hill Carnival. Here a differentiation with respect to the boundary condition of the parade route is possible. In the case of periodic boundary conditions (*e.g.*, London Notting Hill Carnival), the procession occupies the entire pathway at $t = 0$; in open boundary conditions the leader of the parade has to reach the end of the pathway first until it is fully occupied by the procession (*e.g.*, Cologne Rose Monday parade). Based on the analysis of GPS data of the Cologne Rose Monday procession of 2014, this work is intended to make an initial contribution to the understanding of the kinematics of processions with open boundaries. The Cologne Rose Monday parade is outstanding because of its length, prominence, and an excellent representative for processions with open boundaries.

After a brief description of the procession, the collected GPS data are discussed. The following section describes

(a) E-mail: petros.polichronidis@uni-due.de

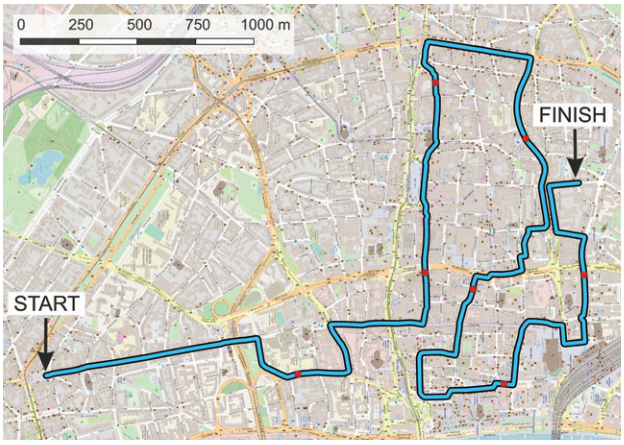

Fig. 1: (Colour online) Pathway of the Rose Monday carnival procession in Cologne from 2014. The distance to the beginning of the pathway is marked for every whole kilometre. Map data copyrighted by OpenStreetMap contributors and available from `https://www.openstreetmap.org`.

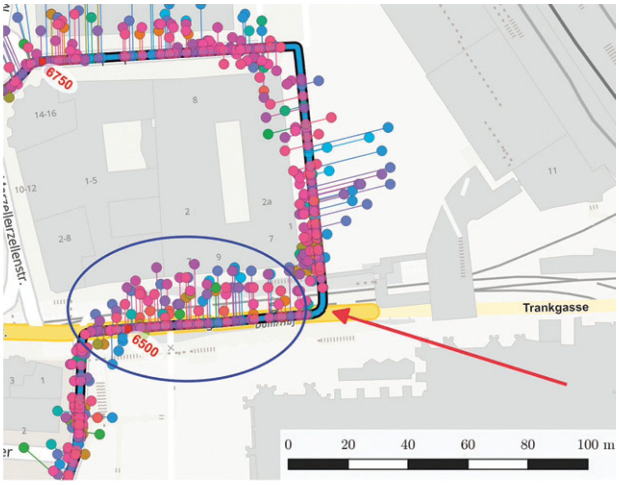

Fig. 2: (Colour online) Representation of the measuring points in the area of the Cologne main station forecourt and the Cologne Cathedral. The map matching error correction creates data gaps at narrow curves (red arrow), shading effects through the Deichmannhaus and the Cologne Cathedral (blue ellipse). Map data copyrighted by OpenStreetMap contributors and available from `https://www.openstreetmap.org`.

the special kinematics of the 2014 parade. Subsequently, a parade group model is presented, which is based on the Nagel-Schreckenberg model [1] and capable to reproduce the observed phenomena in simulations.

Cologne Rose Monday parade. – Processions have taken place for diverse reasons at least since the antiquity [3]. Carnival, military, pride or St. Patrick's Day parades are just a few of the many different manifestations. With a length of approximately 10 km and about 11000 participants, the Rose Monday procession in Cologne is, to our knowledge, the longest in the world (see fig. 1) [4]. It has a highly heterogeneous composition and consists of costumed groups on foot, dance groups, musician groups, child groups, horses, horse-drawn carriages, tractors, carnival floats, support vehicles and others. In a strictly defined order, they run within their carnival society over the 7.6 km long pathway. It meanders through pedestrian zones and the city road network which is closed for common traffic on this day. The procession is headed by the police, immediately followed by a fire engine, which leads the parade with a specified velocity of 2.3 km/h. At the rear end, the Carnival Prince marks traditionally the grand finale of the parade. Since the parade itself is longer than the pathway, the fire engine passes the end of the pathway, while the Prince is still waiting to enter the path at the rear end of the procession. Normally in other cities the parade length is shorter than the parade route, so the situation in Cologne is particularly interesting.

Due to the size of the parade, the process of entering and exiting the pathway has to take place in an orderly manner. But due to different and unpredictable influences, a deviation from the planned moving out times is observed. In addition to these delays, the measured travel times show a monotonously decreasing time span from 3 h 48 min for the foremost participant to 2 h 32 min for the Carnival Prince. If the parade is interpreted as a long, one-lane traffic jam, the assumption can be that the travel time will be lengthened due to delays, the later a participant enters the pathway. The further back a participant is located in the parade, the more frequently he has to stop because of velocity breakdowns in front of him, since the number of stops is accumulated to the rear. These deviations point out the difficulty to predict the duration of such an event.

GPS data. – In order to ensure a smooth and safe course of the event, the Festive Committee is supported by an orderly radio concept. Radio operators within parade groups on the pathway are mostly equipped with GPS-capable radio devices. These allow a GPS tracking of the baggage wagons of most of the carnival clubs and provide information on the movement of the parade.

The analysis is based on provided GPS datasets from the 2014 parade which were stored with a temporal resolution of 30 seconds. Unlike the datasets for the other years, the one from 2014 does not show any massive traffic jam affecting the procession's temporal contraction. Out of 65 carnival societies 29 were equipped with radio devices. Due to the fact that the geographical coordinates measured by the GPS detection method deviate from the true positions of the parade groups, a correction is necessary. The measured positions of the groups are matched with the local information on the pathway. This process is well-known as map matching and is used in a variety of applications typically working with some form of geographical information system. The algorithm used here takes into account the pathway and the GPS measurement points on the digital map and determines positions on the pathway, which are most likely to correspond to

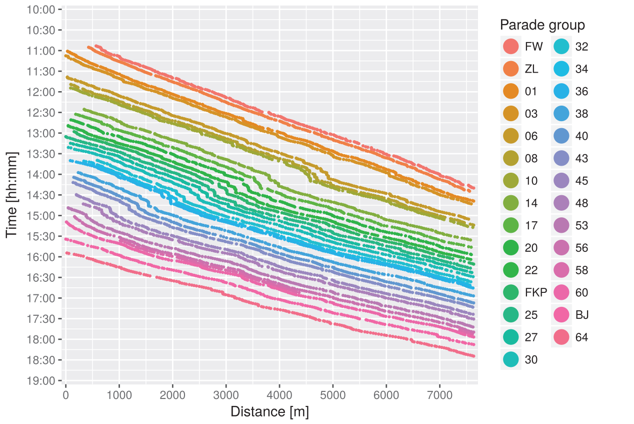

Fig. 3: (Colour online) Time-distance diagram of the Cologne Rose Monday parade from 2014. The trajectories are coloured according to GPS groups (see legend).

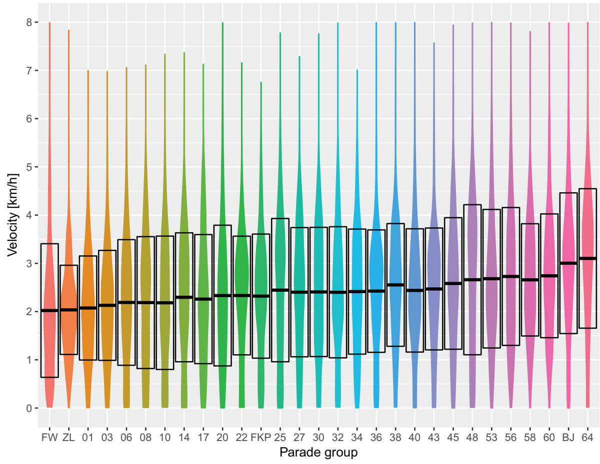

Fig. 4: (Colour online) Velocity distributions for each GPS-equipped parade group for the dataset from 2014. The boxes in the diagram represent the standard deviation and the thicker lines within the boxes the arithmetic mean of samples of the respective distribution.

the true positions of the groups [5]. This orthogonal projection thus determines the nearest point on the path for each data point.

Figure 2 shows a map section in the area of the Cologne cathedral in which raw data and projection points are depicted. The blue ellipse marks a section of high-rise buildings on the pathway, which causes a shading effect and a systematic displacement of the position determination, also described in [6]. Deviations in the transverse and longitudinal directions can be observed here. The displacement in the longitudinal direction, *i.e.*, along the parade's path, changes the spatio-temporal order of the measurement points. This circumstance is most pronounced in the map matching at narrow curves or in regions where the distance between parallel sections is smaller than the inaccuracy of the GPS position determination. An algorithm was developed to filter only the measuring points, which are in ascending spatio-temporal order.

Traffic kinematics. – Figure 3 shows the time-distance diagram illustrating the movement of the recorded carnival groups in the procession. It is a plot of time against the covered distance, whereby the x-axis represents the value range of the pathway and the time values are inverted on the y-axis. The legend on the right side of fig. 3 identifies the colour assignment of the carnival group ID to the trajectory. The top trajectory represents the foremost participant in the procession (fire engine with group ID *FW*). Traffic kinematic effects whose durations are smaller than the temporal resolution of the GPS measurement of 30 s are not visible. In addition to velocity interruptions occurring rarely in time and space, a structured distribution of these measuring points can be seen in time between 1:30 pm and 3:30 pm and in distances between 0 m and 5000 m. This is caused by the propagation of a disturbance, which is triggered within the first four groups and develops into a traffic jam. The jam front propagates over the following participants and temporarily divides into a traffic jam wave with two fronts until it dissolves when it reaches the first kilometre of the pathway. The reason for the standstill is not documented, but various events further ahead in the parade can be assumed as a cause. The occurrence of an ambulance in service, no longer roadworthy vehicles on the pathway or general pathway obstructions (too far protruding stands or path areas with missing caution tape) reduce the pathway width thus influencing the traffic flow. There are also generic standstill-inducing events like dance performances of the dance groups or the candy dispensing of most of the foot groups. These occur throughout the pathway randomly distributed, but they are concentrated in the areas of increased visitor traffic and especially in front of the grandstands of the participating carnival societies.

Figure 4 shows the velocity distributions determined for the dataset from 2014. The specific coloured areas outline the frequency distributions of the velocities for each group. The boxes in the diagram represent the standard deviation and the mean line within the boxes is the arithmetic mean of samples of the respective distribution. The monotonically increasing course of the average velocities with increasing parade group ID is remarkable here. The leader of the parade has been able to almost constantly keep its predetermining velocity of 2.07 km/h in this year. The calculation of the mean velocity for this parade group yields 2,079 km/h. In addition, at $v = 0$ km/h, directly above the x-axis, the width of the distributions decreases for increasing group ID. An exception is the group with the ID *ZL*, which has followed the preceding group almost ideally or has been able to move with a nearly constant velocity. The standard deviation for the average velocity of this group is less than that of the leader of the parade. From this group on, the variance of the distributions increases so that the distribution of the group *20* has almost the same standard deviation as the leader.

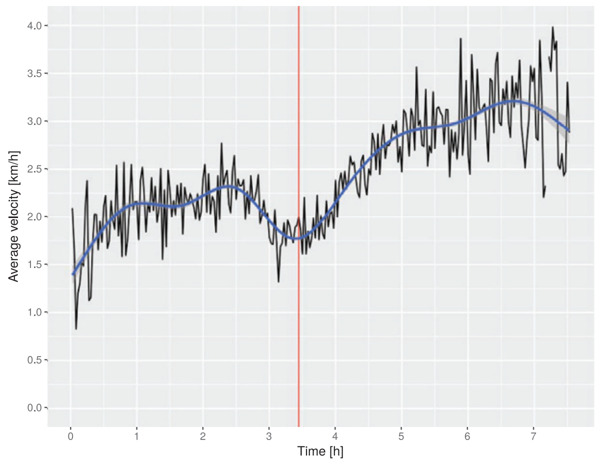

Fig. 5: (Colour online) Velocity-time diagram: the black line represents the current velocity of the procession and the blue line an interpolated course. The width of the grey shaded blue line corresponds to the quality of the interpolation. The red vertical line marks the time at which the fire engine reaches the end of the pathway. After this time, the velocity of the parade increases.

Furthermore, the distributions show different shapes. Some have broad distributions with a constant width over large velocity ranges. At higher velocities (>8 km/h) almost no values are found. Such high velocities are occasionally obtained, because some of the GPS devices are carried in motorized vehicles which cannot drive constantly at such low velocities. They normally over-accelerate and coast or brake in order to adjust their driving speed. The distribution curve of the leader FW is also noteworthy. It shows in comparison to those of some other groups (*e.g.*, 30, 32, 58) a distribution with two local focal points. This is an indication that some of the participants can instantaneously accelerate or decelerate to their target velocity. On the basis of the collected data, however, no further statements regarding the dependence on the participant's traffic characteristics can be made via these distributions.

In another illustration, a partial contribution for the increasing velocities becomes clear. Figure 5 shows the course of the average velocity of the whole parade as a function of time. The arithmetic mean of the velocities of all groups was calculated for intervals of 1 minute and plotted against time. The blue line shows a smoothed approximation of this curve. The gray shaded area around the blue line represents a measure of the accuracy of the interpolation. The red line marks the moment at which the leader reaches the end and is being moved out of the pathway. At the beginning and towards the end of the event, the determined velocity has strong fluctuations, which is mainly due to the small number of groups on the path. The extent of the velocity fluctuations follows the sample size. At the beginning, the average velocity rises to 2.07 km/h specified by the fire engine. The fact that the procession does not already have the velocity of the fire engine at the beginning is caused by an event that can be seen in the time-distance diagram in fig. 3 during the first hour. On the first kilometre of the pathway the carnival procession passes the recording area of the *WDR*, where it is broadcast live to public-law television and the internet. In the course of this, the participants are waving constantly into the cameras to be seen by their loved ones. This acts as a stationary bottleneck that affects the velocities in the first hours and often stops the parade entirely. At later times an average velocity is obtained which corresponds approximately to that of the fire engine. At around 3.5 h, fig. 5 shows a local minimum that is dominated by the mentioned traffic congestion. The velocity does not fall to 0 km/h here, since the part not affected by the disturbance continues. This is where the exit time of the fire engine is located. After it exits, a considerable increase of the average velocity is observed, which is partly responsible for the shortened travel times of the subsequently introduced groups.

Similar observations were made by Tomoeda *et al.* in the movement of people in queues [7]. A smooth movement of a queue depends on the leader's escape velocity (faster than, same velocity as or slower than the follower). A faster leader generates vacant space, a slower leader limits the walking velocity of the follower, so that there seems to exist an optimal escape velocity. A movement at this velocity should conserve the spatial distribution of the headways between the participants during the procession. An increase of the velocities as described in fig. 4 thus is partly caused by the spatial contraction of the parade and partly by the missing velocity-presetting leader. The contribution of the latter in the study from Tomoeda *et al.* is difficult to estimate due to the lack of data. However, the absence of a velocity presetting unit results in an average velocity of each group which depends on system-typical characteristics.

Parade group model. – One motivation of this work is to develop a cellular automaton model for groups in a procession based on the Nagel-Schreckenberg model [1] and to qualitatively reproduce the observed phenomena. This can serve to optimize the capacity and thus the traffic flow of the parade. In addition, the duration of processions could be estimated better. Since the procession has different characteristics than the mere highway or road traffic, a modified Nagel-Schreckenberg model was developed. It depicts the kinematics of groups in festive parades. One aim is to prove the temporal contraction caused by the missing fire engine presetting the velocity. Carnival processions, however, are very diverse regarding individual participants. In addition to pedestrians there are horses and motorized vehicles among the participants. Since the referring data does not provide any information about class-specific characteristics, a model solely of parade groups is presented here. The spatial discretisation in the model is determined by maintaining the temporal

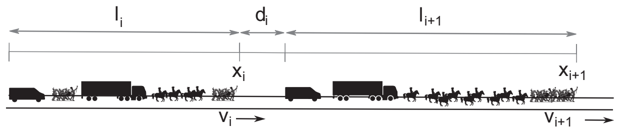

Fig. 6: Graphical representation of the parameters in the presented parade group model: the proper group length l_i, its velocity v_i and its position x_i. The headway to the foregoing group d is an abbreviation of the relation $d_i = x_{i+1} - l_{i+1} - x_i$, with i marking the index of each group.

update interval of 1 second. Based on the target velocity of the fire engine from 2014 (2.07 km/h), this corresponds to a cell size of 1 cm. According to the length of the pathway, the cell space comprises 763300 cells. As a set of states a class "parade group" is implemented which has the parameters position x_i, velocity v_i, headway d_i, proper length l_i, waiting time τ_i, maximum velocity $v_{\max,i}$ and the time point of moving on the pathway. A graphical representation of the parameters involved are shown in fig. 6.

By modeling groups as agglomerates of different participants, they have a time-dependent proper group length $l_i(t)$ of several hundred metres in this model. The spatial compressibility results from the headway of each participant. Small gaps occur within foot groups or larger ones between the parade groups. In summary, a compressibility to a minimum length $l_i^{\min} = \lambda \cdot l_i(0)$ results depending on the composition of each group. Based on video recordings, it was estimated that the relative change of the proper group length in relation to the length in free traffic is about 80%. This value does not meet the requirement to assign each group an individual compressibility. A contraction occurs when a participant comes to a standstill and the following runs into it. A foot group, for example, contracts as soon as its front row stops. The following rows close up the ranks to a minimum distance, so that the contraction runs with a velocity that corresponds to that of the following participant. The process is almost identical when the front rows start to move. At these low velocities for pedestrians, slowing-down and accelerating to the targeted velocity are almost instantaneously possible. Assuming that a contraction process in a foot group takes about 5 seconds, a contraction factor $\kappa = 0.955$ is chosen to complete a contraction to 80% of the original length in 5 seconds. The expansion process begins as soon as the front starts to move and ends as soon as the original proper length $l_i(t = 0)$ is reached again.

As a further special feature, the model has a foremost participant that drives ahead at a constant velocity $v_{\text{leader}}^{\text{target}}$. The other groups follow with maximum velocities $v_i^{\max}$ stochastically determined by random numbers. The random numbers are drawn from a normal distribution having a mean value that corresponds to the targeted velocity of the fire engine while only accepting velocities that also occur in the empirical data. The stochastic allocation of the maximum velocity is justified by the fact that

Table 1: Parameters and values in the presented parade group model.

Parameter	Value
Spatial discretisation Δx	0.01 m
Temporal discretisation Δt	1.0 s
Stopping probability P_{stop}	0.001
Parade group max. velocity $v_i^{\max}$	chosen stochastically
Velocity increment Δv	0.18 km/h
Proper group length l_{group}	variable 100 m–800 m
Parade leader target velocity $v_{\text{leader}}^{\text{target}}$	2.052 km/h
Minimal contraction λ	0.8
Contraction factor κ	0.955
Waiting time Δt_{stop}	60 s
Countdown parameter waiting time τ	60 s–0 s

almost all participants have to run a velocity for which they have to throttle their speed. The targeted velocity is always greater than the velocity of the first participant of 2.3 km/h (2015–2017) or 2.07 km/h (2013, 2014).

To model the congestion effects observed in fig. 3, a dawdling parameter ξ is introduced, which causes the parade groups to stand still with a certain probability P_{stop} and stay in this state for at least 60 seconds. Often there are processes during the procession, which require a stop and a subsequent waiting (dance interludes, filling up candies and other thrown material). These modified acceleration rules ("slow-to-start") have been examined for different traffic flow models [8]. In a way this can be interpreted as an extremely delayed anticipation, as described for cars in [9] after braking processes. The value of the waiting time Δt_{stop} of 60 seconds was selected based on measurements of the duration of the dance performances and filling processes on the baggage vehicles on the basis of video recordings. An overview of the parameters used in the model is given in table 1.

With the previously declared parameters now the rules can be set up, followed by the agents in the simulation. The fire engine has the index $i = 1$ and remains unaffected by the first two rules, while only rule 3 is applied. At the end of the pathway the participants are taken out of the simulation, so that they do not hinder the following agents. Due to the single-lane nature of the procession, a serial update is used to emulate a more realistic process. In the following the rules of the parade group model are explained.

1) *Accelerate/braking*: The first step is to check if the group stops and if its waiting countdown has expired ($\tau_i(t) = 0$). If this is not the case, the waiting time countdown $\tau_i(t)$ is reduced per time step by one. Otherwise, the velocity increases by an increment Δv up to the maximum velocity $v_i^{\max}$, or in the

case $v_i(t) > d_i(t)$ the velocity is set to the headway $d_i(t)$. The waiting time countdown $\tau_i(t)$ remains at zero,

$$v_i(t+1) \overset{i \geq 1}{=} \begin{cases} 0, & \text{if } v_i(t) = 0 \text{ and } \tau_i(t) > 0, \\ \zeta_i(t), & \text{else,} \end{cases} \tag{1}$$

with $\zeta_i(t) = \min(v_i(t) + \Delta v,\ v_i^{\max},\ d_i(t))$,

$$\tau_i(t+1) \overset{i \geq 1}{=} \begin{cases} \tau_i(t) - 1, & \text{if } v_i(t) = 0 \text{ and } \tau_i(t) > 0, \\ 0, & \text{else.} \end{cases} \tag{2}$$

2) *Stopping of the groups/dawdling*: A dawdling probability P_{Stop} generates random stoppage. If the dragged random number ξ is smaller than the probability P_{Stop}, the velocity is set to zero. Otherwise, the velocity determined from the previous step is assigned to the next time step. In addition, depending on the current state of motion, a contraction or expansion of the proper group length is applied,

$$v_i(t+1) \overset{i \geq 1}{=} \begin{cases} 0, & \text{if } \xi < P_{\text{Stop}}, \\ v_i(t), & \text{else,} \end{cases} \tag{3}$$

$$\tau_i(t+1) \overset{i \geq 1}{=} \begin{cases} \Delta t_{\text{Stop}}, & \text{if } \xi < P_{\text{Stop}}, \\ 0, & \text{else,} \end{cases} \tag{4}$$

$$l_i(t+1) \overset{i \geq 1}{=} \begin{cases} \epsilon_i(t), & \text{if } v_i(t) = 0 \text{ and } l_i(t) \neq \lambda \cdot l_i(0), \\ \mu_i(t), & \text{else,} \end{cases} \tag{5}$$

with $\epsilon_i(t) = \max(\kappa \cdot l_i(t),\ \lambda \cdot l_i(0))$ and $\mu_i(t) = \min(l_i(t) + v_i(t),\ l_i(0))$.

3) *Moving the groups*: Finally the group is moved with the velocity determined in the previous steps,

$$x_i(t+1) \overset{i \geq 1}{=} x_i(t) + v_i(t+1). \tag{6}$$

In the simulation, the structure of the procession was taken from 2014 (29 parade groups with corresponding proper length). The model reproduces a temporal contraction of the whole procession of 22.4%. The leader of the parade needs 3 h 43 min and the last participant 2 h 47 min to reach the end of the parade's path. This corresponds to the reduction of the duration of the event from 5 h 06 min at the beginning and 4 h 10 min at the end of the pathway. The calculation based on the GPS data results in a temporal contraction of 22.2%. It yields travel times of 3 h 40 min for the leader and 2 h 28 min for the last participant, which corresponds to a temporal contraction of 48.6%. The travel time of the first participant in the simulation is 3 h 43 min and that of the last one 2 h 47 min, which is equivalent to a temporal contraction of 33.5%. Qualitatively, these observations are repeatedly reproduced, but the concrete values have no general validity. A quantitative comparison averaging over empirical data obtained under similar conditions would be necessary and obviously not feasible.

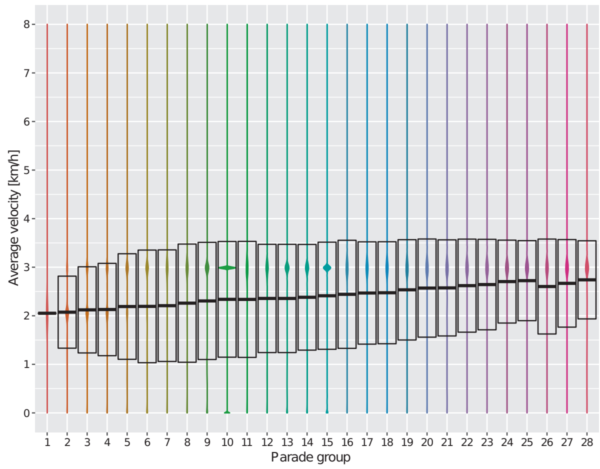

Fig. 7: (Colour online) Velocity distributions for each agent from the simulation. The boxes in the diagram represent the standard deviation and the thicker lines within the boxes the arithmetic mean of samples of the respective distribution.

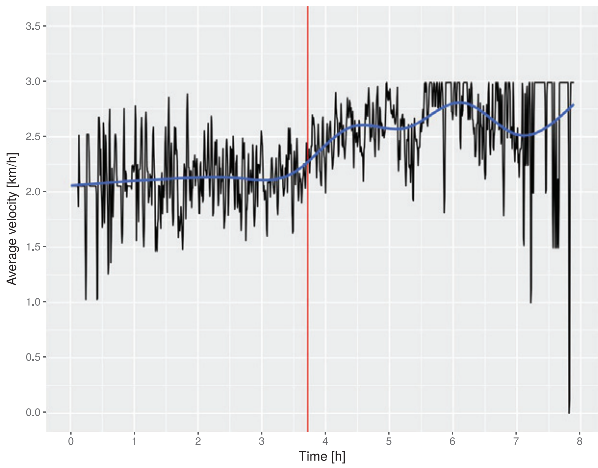

Fig. 8: (Colour online) Velocity-time diagram: the black line shows the course of the average of the velocities, which has been formed over 60 seconds. the blue line represents an interpolation. The red line indicates the time point at which the foremost participant leaves the pathway in the simulation.

The velocity distributions of the groups in the simulation are shown in fig. 7. As with the travel times, the velocity dependence observed in fig. 4 is only qualitatively reproduced for the mentioned reason. The mean values of the distributions increase with ascending parade group ID. Deviations from the sample, like the mean velocity of the parade group ID *26*, are stochastic in nature. The standard deviation of the respective distribution increases until group ID *11*. This corresponds to the parade group, which enters the pathway when the parade leader has already left the pathway. From there on the standard deviation decreases. Clearly visible are the Gaussian-like emphases of the distributions above the mean values. In addition, velocities of 0 km/h are relatively frequent. The mean values are essentially composed of the measured values at 0 km/h and the distribution is above the mean values. The parade groups adopt velocities between these ranges only during acceleration and braking processes. The distributions in fig. 4 also show these emphases, but the adopted velocities are more widespread than those from the simulation.

The examination of the proper group lengths reveals that they are obtained on average, since the contraction and expansion processes are nearly symmetrical in this model.

Figure 8 shows the velocity-time diagram acquired from the simulation data. The black line indicates the course of the over 30 seconds averaged velocity. The blue line shows the interpolated course of the black curve. An increase of the average velocity of the parade can be observed, when the leader of the parade leaves the pathway (red line). There are also velocity fluctuations that are stochastic in nature. Velocities above the stochastically selected maximum do not occur. This upper bound can be found in fig. 8. The groups do not adopt velocities greater than 3 km/h.

Conclusion. – In this work GPS traffic data from the Cologne Rose Monday parade 2014 were analyzed. An algorithm was used by which the processed data could be corrected. Based on the remaining measurement points, a statistical analysis was performed. Different travel times were determined for the last and the first participant of the parade. Differences in the velocity distributions are revealed, which depend on the parader's position within the procession. This result is partly due to the missing fire engine presetting the velocity, after it has left the parade's pathway. Based on the results of the data analysis, a parade group model as a modified Nagel-Schreckenberg model was presented. With its help, it was possible to reproduce the determined velocity profile of the parade. In addition, a spatial contraction of the whole procession that also causes an increase in velocity towards the rear end of the parade is to be assumed. In order to quantify the contribution of the spatial contraction, a more detailed version of the parade group model will be developed and presented in the near future. This will take into account the class-specific traffic dynamics of each participant, as well as interactions with the infrastructure (attending visitors, grandstands, traffic area transitions, etc.). Furthermore it would be interesting to find the observed phenomena in other procession-like traffic systems (*e.g.*, military brigades, other parades, hiking groups, walking school class in rows of two).

* * *

We would like to thank the Festkomitee Kölner Karneval 1823 e.V. for the cooperation. In particular we are very grateful for providing the GPS data, documents and the many discussions contributing significantly to the development of this work.

REFERENCES

[1] Nagel K. and Schreckenberg M., *J. Phys. I France*, **2** (1992) 2221.

[2] Batty M., Desyllas J. and Duxbury E., *Int. J. Geographic. Inf. Sci.*, **17** (2003) 673.

[3] Beard M., *The Roman Triumph* (Harvard University Press) 2007.

[4] Recordbay-GmbH, *Der Kölner Rosenmontagszug*, Festkomitee des Kölner Karnevals von 1823 e.V., `https://koelnerkarneval.de/zuege/`.

[5] Quddus M. A., Ochieng W. Y. and Noland R. B., *Transp. Res. C*, **15** (2007) 312.

[6] Wang L., Groves P. D. and Ziebart M. K., *Shadow matching: Improving smartphone GNSS positioning in urban environments*, in *China Satellite Navigation Conference (CSNC) 2013 Proceedings* (Springer, Berlin, Heidelberg) 2013, pp. 613–621.

[7] Tomoeda A., Yanagisawa D. and Nishinari K., *Escape velocity of the leader in a queue of pedestrians*, in *Traffic and Granular Flow 2013* (Springer International Publishing) 2014, pp. 213–218.

[8] Schadschneider A. and Schreckenberg M., *Ann. Phys.* (*Berlin*), **509** (1997) 541.

[9] Knospe W., Santen L., Schadschneider A. and Schreckenberg M., *J. Phys. A: Math. Gen.*, **33** (2000) L477.