FLUX-DENSITY TRAFFIC DIAGRAMS OF FORAGING ANTS SUGGEST ABSENCE OF JAMMING EVEN UNDER EXTERNAL PERTURBATIONS

LOS DIAGRAMAS DE TRÁFICO FLUJO-DENSIDAD PARA LAS HORMIGAS QUE FORRAJEAN SUGIEREN AUSENCIA DE "JAMMING" INCLUSO ANTE PERTURBACIONES

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A traffic flux-density diagram consists in a graph were the flux of moving particles (like cars or pedestrians) is plotted as a function of the particle density. In conventional traffic, the presence of a decreasing branch in such diagram means jamming (i.e., particles are crowded so they cannot move anymore or move very slowly). We have measured and constructed a flux-density diagram for trails of foraging ants of the species *Atta insularis*. Our diagrams do not show a decreasing branch, indicating that ants do not reach the jammed state during foraging. Moreover, the jamming-free scenario persists even when the foraging trail is perturbed by abducting ants.

Los diagramas de flujo-densidad consisten en gráficos donde se plotea el flujo vs. la densidad en partículas móviles (como autos of caminantes). En el caso del tráfico convencional, la presencia de una rama decreciente en el diagrama flujo-densidad implica "jamming" (o sea, las partículas están tan aglomeradas, que son incapaces de moverse, o se mueven muy lentamente). En este trabajo, hemos medido y construido diagramas flujo-densidad para filas de forrajeo en hormigas de la especie *Atta insularis*. Nuestros diagramas indican que las hormigas nunca alcanzan el estado de "jamming" durante el forrajeo. Adicionalmente, hemos comprobado que el escenario libre de "jamming" persiste incluso cuando la fila se perturba abduciendo individuos.

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One of the most amazing features of many species of ants are foraging lines that span hundreds of meters from the nest to the feeding sources [1]. Their traffic can be characterized quantitatively by measuring the flow-density diagrams –a tool imported from the field of traffic engineering [2]. In the case of ants, differently from the case of vehicular traffic, the diagram does not show a decreasing branch [3,4], which indicates that jamming does not take place in the former system. In this paper, we offer a preliminary quantification of the traffic in foraging lanes of the Cuban leaf-cutter ants *Atta insularis* [5] by using flow-density diagrams. We perform experiments on natural nests, controlling the ant density by abducting individuals at a fixed point of the foraging lane.

Experiments were conducted on two colonies of the Cuban leaf-cutting ant *Atta insularis*, within the period January - April and September 2014. The nest was located under the pavement of the parking lot at the Institute of Materials Science and Technology (IMRE), University of Havana, and ants foraged every night on a garden located some 100 meters from the nest, partially behind a building. Most of the trajectory of the foraging trail occurred on the surface of the parking lot, especially near curbs and other edges. The experiments were performed between the 22:00 and the 23:00 hours, corresponding to the peak of activity of the colony. That guaranteed the study of the steady state, in which the number of ants coming in and out of the nest per unit time are equal and constant [6,7].

Figure 1 shows our experimental setup: the nest's door is to the left of the photograph, and the foraging trail extends to the right. Two video cameras were used: Camera 1 was near the door, immediately to its right. Camera 2 was 3 meters to the right of the door.

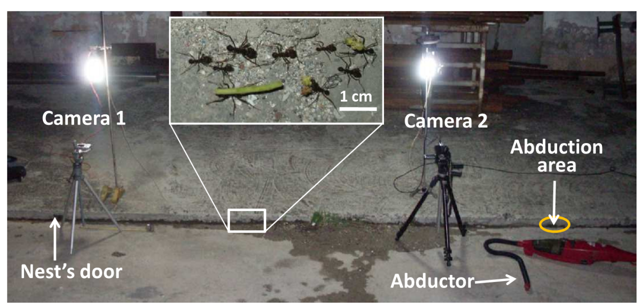

Figura 1. Experimental setup. Camera 1 is near the nest's door, Camera 2 is 3 m to the right of Camera 1, and the abduction zone is 1 m to the right of Camera 2. The Abductor (a standard vacuum cleaner) rests on the ground to the right of camera 2. The inset shows a zoom of the foraging line, where out-bound ants move from left to right, and nest-bound ants (carrying vegetal material) move from right to left.

During our experiments, two interwoven lanes of ants were established: an *out-bound* one of ants moving from the nest to the foraging area (from left to right in Fig. 1), and another of *nest-bound* ants returning from the foraging area to the nest (from right to left in Fig. 1). Our experimental protocol can be described as follows. First, the unperturbed ant trail was filmed by the two cameras for 25 minutes. This serves as baseline for the experiment, where ants showed stationary activity. Then we abducted ants using the vacuum cleaner in an area of 50 cm^2 located one meter to the right of camera 2 (see Figure 1) for either 25 or 30 minutes. Approximately 50 % ants moving in both directions were abducted. The out-bound ants coming from the left that managed to escape the predator, simply returned to the nest. After the time of the abduction, we filmed the activity for another 20 minutes. Under these conditions, two repetitions of the experiment were performed.

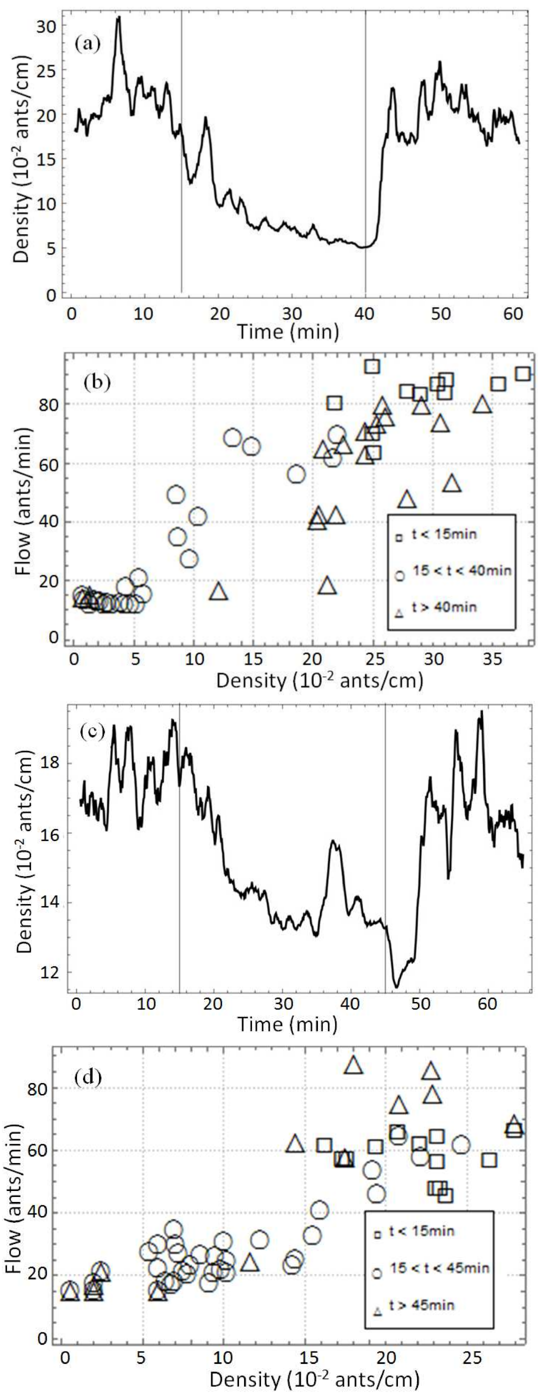

Figura 2. Evolution of the density and flow-density diagrams for ant traffic. (a) and (c) Linear density vs time for abduction periods of 25 and 30 minutes, respectively). (b) and (d) Flow vs. density traffic diagrams corresponding to abductions of 25 and 30 minutes, respectively. The data shown was acquired using camera 2, but the results using camera 1 are qualitatively analogous.

The flow of ants per minute, was determined by taking the time derivative of the cumulative number of ants determined experimentally from Camera 2 (data from Camera 1 gave similar results). To estimate the density of ants in the trail each picture from the video was binarized using an appropriate threshold. Each video frame was converted to gray scale. We chose a threshold intensity to convert all ants into black pixels and the rest into white pixels. The sequence of binarized image was used to relate the amount of black pixels in each frame with the actual amount of ants. This allowed us to construct a calibration curve to estimate the density of ants (in ants per unit length of the trail) from the number of black pixels found in each frame of video (notice that we have included here ants moving either from and to the nest). Figure 2 (a) and (c) show the evolution of the density of ants in time for abduction times of 25 and 30 minutes, respectively. With the flow and the density of ants, we constructed the fundamental diagram of traffic, shown in Figure 2 (b).

We have used different symbols for the point falling before, during and after the abduction period. Before the abduction (circles), ant flow is roughly constant, which is consistent with the fact that it is the optimal foraging flow "collectively tuned" by the colony. During the abduction period (squares) the flow decreases more of less linearly with the ant density, as previously observed *in the absence of abduction* in foraging ants [3,4]. During abduction, we have observed that roughly 50 % of the ants that reached the abduction zone (see figure 1) detected the danger, made a "U" turn, and returned to the nest. Based on our intuition from human behavior, one might expect the occurrence of jamming when those returning ants (presumably "in panic") encounter outbound nestmates moving towards the abduction area. But that was not the case: as mentioned previously, there is not a decrease branch in the flux-density diagram during abduction, which means that there is no jamming even in "panic" conditions. This is consistent with a cellular automata model where ants escaping from the abduction area do not communicate any danger information during their head-head encounters with nestmates moving towards the danger area [8]. Finally, we can see in figure 2 that, after the abduction lapse (diamonds) the flow recovers its "optimal" level as the density increases to its pre-abduction value.

In conclusion, foraging ants submitted to a controlled perturbation always follow a positive slope branch in the flow-density diagram, demonstrating the absence of jamming even in "panic" conditions –at least far enough from the disturbance area. This is consistent with earlier experiments where ants are forced to escape from a cell through thin exits: the evacuation may slow down due to the collective decision to use one of the exits; but jamming does not take place at either exit [5].

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