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# “FLUXES IN CITIES. How a crowd flows in the streets?”

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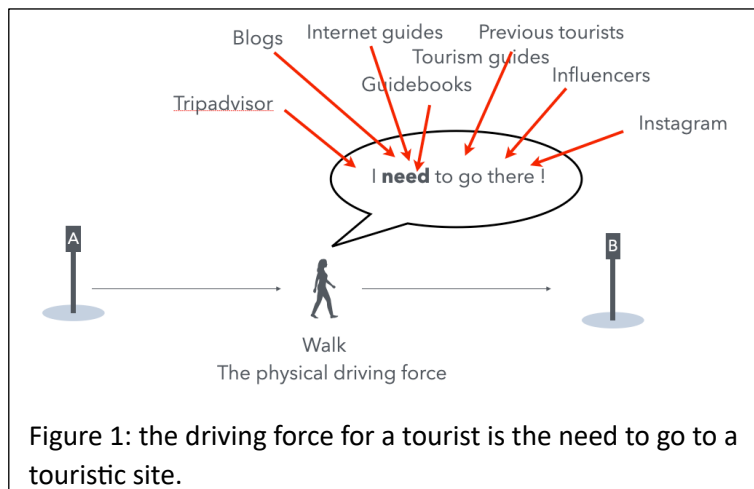
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The topic of the BIP “*Overtourism in global cities. Impacts, challenges and solutions*” seems far from common research topics in a physics or mechanics laboratory. However, there is a strong analogy between the motion of people, cars and buses for tourism and other physical motions such as flow of water or granular material. This short paper introduces common concepts which can be very useful for a geographical study of tourism.

## 1. Flowing objects and driving forces

A flow can be defined as a “collective motion of individual objects”. At a microscopic scale, not visible by eye, H<sub>2</sub>O water molecules move and flow in a collective way. At a larger scale (at a millimetric scale), we are used to observe flows of grains, salt, cereals, sand. And at an even larger scale (now at a metric scale), pedestrians in a street, animals in a field, or cars on a road can be observed as a flow. The great variety of situations where a flow can be observed leads to the need of a universal model with common concepts and ideas.

A flow only exists with something acting as a driving force. In a pipe where water flows, the gravity or a pressure difference creates the flow. The driving force is a mechanical action which “pushes” the objects in a given direction. If the objects are self-propelled, a pedestrian for example, the driving force may be the need to go to a specific place, a touristic place for example [figure 1]. This need is often directed by recommendations, guides, social networks, or “the place-to-be” injunctions.



Cars on a road are also a very good illustration of flow: traffic flows are studied, modeled and theorized as an extension of fluid mechanics with a strong analogy with the basic principles of physics (mass conservation). The equations which describe a traffic flow are solved as wave equations and exhibit some stable solutions (fluid traffic) as well as unstable solutions leading to traffic jams.

The same situation may occur in touristic cities or touristic places because attractive driving forces applies on many people, leading to crowds packed in a limited area. Therefore, there is also a good analogy with physics, where jamming, pressure are relevant keywords to describe a crowd of packed people in a limited area.

## 2. MEASURING FLOW PARAMETERS

A few definitions are necessary to start. An “**object**” is defined as the smallest constituent of the flow and may be an atom, a sheep, a pedestrian or a car depending on the context. When several objects are in a limited area, the **density** is defined as the number of objects per unit of area. Counting the number of tourists in a place leads to a density which is measured in person per square-meter ( $\text{p/m}^2$ ). Another relevant parameter is the **velocity** of objects, with a standard unit of meter per second ( $\text{m/s}$ ) or kilometer per hour ( $\text{km/h}$ ). When the moving objects flow in a channel of limited width (pedestrian in a street for example), the width of the channel affects the flow behavior. Finally, one can define the flowrate which is the product of three parameters: the surface density, the velocity and the width. This gives a flow rate which is measured in  $\text{p/s}$ :

$$\text{Flowrate} = \text{density} \times \text{velocity} \times \text{channel width}$$

For standing people, a very low density is below  $0.5 \text{ p/m}^2$ , a moderate density is around  $1 \text{ p/m}^2$ , and a very high density is above  $2 \text{ p/m}^2$ , with a maximum of 4 to  $5 \text{ p/m}^2$ . The typical walking velocity of an adult in a free space is roughly  $4.5 \text{ km/h}$ , but this velocity may be strongly affected by the density or by physical obstacles. For a touristic city, the channel width is simply the width of the pedestrian street.

Counting people in a street may be achieved using mobile phones or video monitoring. In a recent paper [1], the geolocated and anonymized data from mobile phones were successfully used to map the density in a touristic part of Lisbon. Since each mobile phone is constantly emitting and receiving signals from antennas, the density of these signals (361 million for one week) were drawn on the city map. Another frequent measurement technique is the use of street cameras [2], with a quite complex algorithm to count the number of heads and faces from each frame of a video sequence.

Velocity measurements of pedestrians in a street can be achieved cleverly using the Particle Image Velocimetry (PIV) technique. In this technique, the individual velocity of each object is not measured, but two successive images of a video sequence are compared with a correlation calculation. This technique has been used for example to measure the crowd velocity during a marathon running race.

## 3. MODELLING

The correlation between the density, velocity and flowrate is roughly guessed from simple observations. If a pedestrian is alone in a street, the density is close to zero and the velocity is the free walking velocity, close to its maximum value. Since the density is very low, the flowrate has also a low value. On the contrary, when a street is very crowded, the density is very large, and the average velocity is quite low because of the lack of free space around each person. Again, the multiplication of a large density and a low velocity leads to a low flowrate. As suggested on figure 2, there must exist an optimum point when the correlation between the density and the flowrate is drawn. This assumption is a common observation in traffic flows, especially for cars on

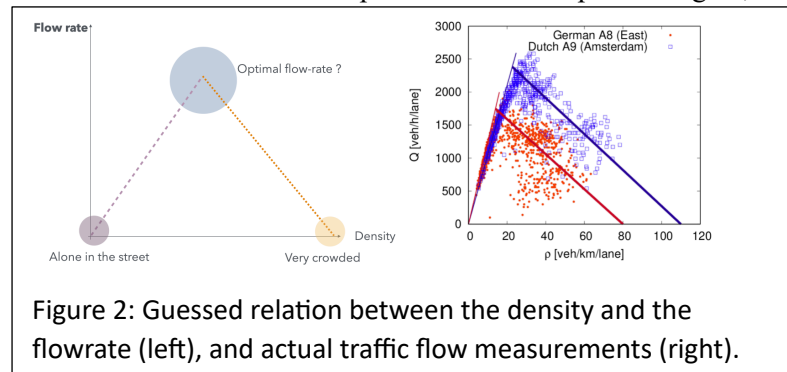


Figure 2: Guessed relation between the density and the flowrate (left), and actual traffic flow measurements (right).

highways. A difficulty is to derive a mathematical expression representing these observations and to extend this model to different situations.

Another way of modelling the behavior of a flowing crowd is to make an analysis at the scale of the object. With the analogy of the Newton's law in physics, a motion equation for each object (a pedestrian) may be written as the following:

$$\text{Acceleration} = \text{sum of the driving forces}$$

The acceleration (variation of the velocity) is thus affected by different forces such as the social force (an attractive force towards a nice place), the interaction force with other objects (repulsive force to prevent bumping), interaction force with walls or obstacles (again a repulsive force to prevent bumping), or a hindering force (a slowing force when approaching a hazard). While this concept is quite simple, difficulties arise when dealing with many interacting objects.

#### 4. FIELD STUDY

During the field trip to Toledo on May 29<sup>th</sup>, 2024, an alternative approach for measuring the local impact of tourism was proposed. This approach assesses the feasibility of density measurements through acoustic sampling and geo-located measurement of noise levels. The noise level (in decibels, dB, the standard unit) expresses how the environment is noisy. A 0 dB noise level is the threshold of auditive perception for a human ear, the range 20-40 dB is representative to very quiet places, whereas a noise level close or over 80 dB represents very noisy places, where a simple face-to-face conversation may be difficult. Very strong noises (over 110 dB) may be found in concert halls, in industrial plants or close to airports.

As shown below on figure 3, a few examples of noise level sampling in the city of Toledo shows a large variation, from a very quiet place (Monasterio de San Juan de los Reyes, 46 dB) to a very crowded environment (a small street leading to the Cathedral, at this time filled with children, 82 dB).

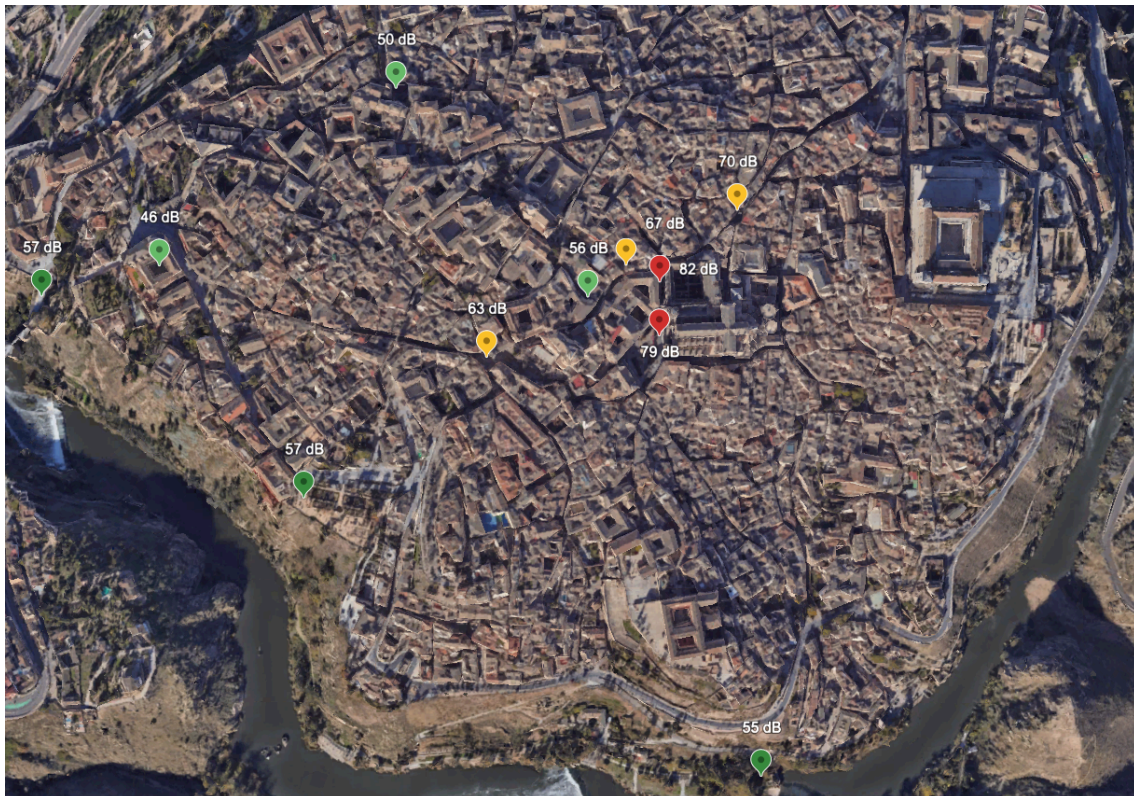


Figure 3: Examples of noise levels measured in the historic city center of Toledo, Spain. The color scale expresses the noise intensity.

## 5. SOLUTIONS TO PREVENT JAMMING

In overcrowded cities or places (Venice, Barcelona, Amsterdam for examples), the touristic experience quality has recently diminished. One of the reasons of this low quality is the difficulty to access to some places, or the waiting time to enter a building or a site. If no flow control policy exists, jamming of pedestrians may occur in narrow touristic streets. One solution would be to invite people to take diverting routes with signs and posters. But the physical study of flows of grains may also help to find innovative solutions. Studies on flows of grains out of a silo or sheep escaping a room show that jamming occur over a critical density localized at the outlet or doors. One paradoxical solution is to put a rigid obstacle not too far from the exit to prevent a too large density. This keeps a fluid and constant flow without jamming or blockage.

Apart from this physics-inspired solution, the authorities managing famous places recently try to reduce the number of visitors with a toll (Venice, Italy), or even a limitation of daily tickets (access of Machu Picchu site, Peru). This helps obviously to reduce the daily entering flow but does not prevent the local high-density jamming due to the sheep collective behavior of tourists.

Tourism is a field of study for geographers, but since it deals with moving objects, it is also a very interesting topic for physicists. With a reasonable analogy, mathematical models for fluid flows or traffic flows may be transposed to the behavior of crowds moving with the fear of missing out in touristic sites. Further research is needed to clearly establish the limit of this analogy since the psychology of individuals stays a tough problem as soon as many neighboring interactions are present.

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