***Contribution of Ruwim Berkowicz to the TRAPOS WG-TPT meeting in Cambridge, 25.02.2000:***

## Human Approach to Traffic Produced Turbulence

In this note we describe a method for derivation of the traffic produced turbulence, which makes use of a concept based on treating the traffic as consistent of individual vehicles, and not as a “monster”.

Let’s first consider a situation with no wind. If we look on a time record of the turbulence measured at some location in the street, it will show a periodic pattern (Figure 1).

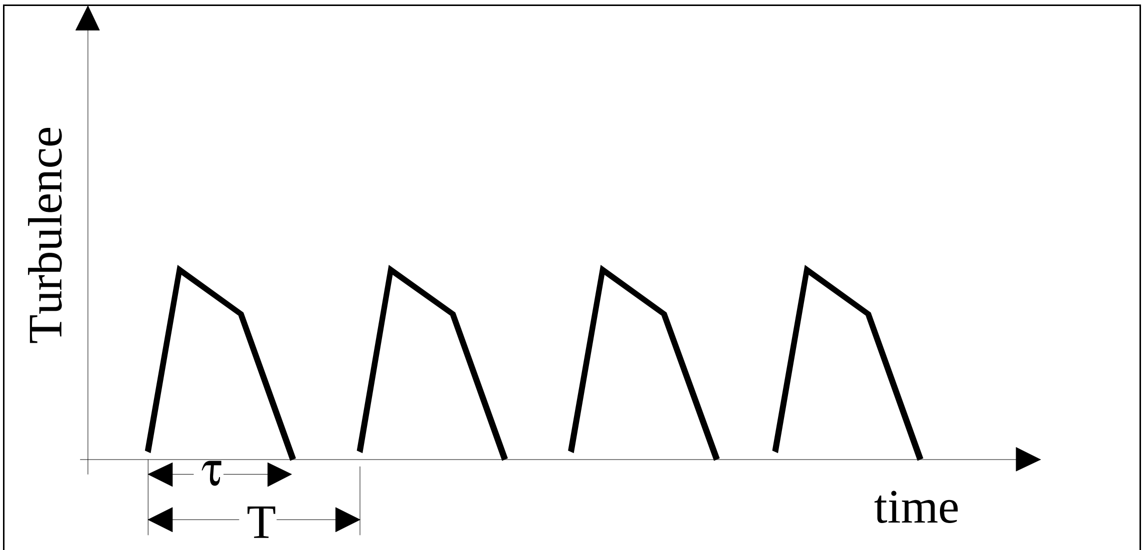


Figure 1.

In Figure 1, T is the time period of passing vehicles and τ is the life time of the turbulent wake created by a single vehicle.

$T=1/N_t$, where $N_t$ is the vehicle flow per time (veh/hour)

$\tau=L/v$, where $L$ is the length of the turbulent wake and $v$ is some characteristic velocity scale of the turbulence in this wake.

Let’s now consider the case $\tau<<T$, i.e. a case with no overlapping wakes. The turbulence in each such separate wake is given by,

$$e = C_D A_t V^2 /(h \cdot W) \tag{1}$$

$C_D$ is the drag coefficient
$A_t$ is the frontal area of vehicles
$V$ is the vehicle speed
$h$ is the height of the vehicles (or the height of the wake(?))
$W$ is the width of the street canyon

It is assumed here that the turbulence is produced in a layer of height $h$ and that it is spread over the whole street width $W$.

Equation (1) describes the turbulence created by a single vehicle only. For calculation of pollution dispersion in the street we need an average turbulence level $E$. If the averaging time is sufficiently long, that means if *averaging time >> T* then we can write

$$E = e \cdot \tau / T \tag{2}$$

Inserting (1) into (2) and using the definitions of T and $\tau$, we obtain

$$E = C_D \frac{A_t L}{h \cdot W} V^2 \frac{N_t}{v} \tag{3}$$

As long as the wakes created by the single vehicles do not overlap (i.e. $\tau << T$) it is logical to assume that

$$v = \alpha_1 \cdot V \tag{4}$$

Inserting (4) into (3) we obtain

$$E = C_D \frac{A_t L}{h \cdot W \alpha_1} V N_t \tag{5a}$$

This is the formula used in OSPM, but with the vehicle related constants given by some empirical values. Furthermore, only the vertical turbulence component, $\sigma_w$, is modelled in OSPM.

Expression (5a) can also be written in terms of the traffic density parameter, $n_t$, using the relationship

$$N_t = n_t \cdot V$$

$$E = C_D \frac{A_t L}{h \cdot W \alpha_1} \cdot n_t \cdot V^2 \tag{5b}$$

<u>Let's now consider the case $\tau >> T$, i.e. a case with totally overlapping wakes</u>. This situation will occur whenever the traffic is very dense (small $T$), or when $\tau$ becomes large. The traffic starts to behave now as a "big monster". Whatever is the reason for this behaviour, it is logical to assume in this case that the characteristic velocity scale of the traffic created turbulence, $v$, is related to the average turbulence level $E$,

$$v = \alpha_2 \sqrt{E} \tag{6}$$

Inserting (6) into (3) we obtain

$$E = C_D \frac{A_t L}{h \cdot W} V^2 \frac{N_t}{\alpha_2 \sqrt{E}} \tag{7a}$$

or

$$E = \left[ C_D \frac{A_t L}{h \cdot W} V^2 \frac{N_t}{\alpha_2} \right]^{2/3} \tag{7b}$$

Replacing the traffic flow, $N_t$, by traffic density, $n_t$, (7b) can be written as

$$E = \left[ C_D \frac{A_t L}{h \cdot W} \frac{n_t}{\alpha_2} \right]^{2/3} \cdot V^2 \tag{7c}$$

Expression (7c) corresponds to the "Platte Modelling Concept" (PMC).

Let's now consider another extreme situation, <u>when the turbulence in the street is dominated by the ambient wind</u>. In this situation the characteristic velocity scale, ν, is most likely related to the ambient wind speed $U$.

$$v = \alpha_3 \cdot U \tag{8}$$

Inserting (8) into (3) we obtain

$$E = C_D \frac{A_t L}{h \cdot W} V^2 \frac{N_t}{\alpha_3 U} \tag{9a}$$

or

$$E = C_D \frac{A_t L}{h \cdot W \alpha_3} \cdot n_t \cdot \frac{V^3}{U} \tag{9b}$$

Comparing (9b) with (5b) we can see that transition from a regime dominated by traffic (human) to the regime with domination from the ambient turbulence will take place when

$$\frac{\alpha_1 V}{\alpha_3 U} < 1 \tag{10}$$

If we take into account that $\alpha_1$ is most likely of the order of 1 and $\alpha_3$ is of the order of 0.1 then for normal traffic conditions ($V \approx 10$ m/s) the wind dominated regime will not be of any practical interest (?).

However, it's still not clear how the length scale of the turbulent wake behind the vehicles, $L$, depends on the level of the external turbulence. In this case the external turbulence covers both the ambient turbulence (proportional to $U$) and also the turbulence created by the other vehicles (the "monster" case). The experiments conducted by the Surrey group with a "step-down" wake indicate that the length of the wake decreases with increasing turbulence level of the approaching flow. If these results can be applied to the vehicle wakes then some dependence of *L* on the turbulence level in the street must be taken into account.

There are still more unanswered questions:

1. How to describe the transition from the “human” to the “monster” regime?
2. Can the observed behaviour of the concentrations be used to make conclusion on the turbulence dependence on traffic?

The field data (concentrations) provide an equally good (or bad) fit to both the OSPM (Eq. (5)) and the PMC (Eq. (7)) approaches. The wind tunnel data are more in favour of the PMC approach. Both indicated a significant influence of the traffic produced turbulence on the observed concentrations. However, there is a substantial difference between the field and the wind tunnel experiments. The traffic in a street will not only result in a periodic increase of the turbulence but also in a periodic emissions. Roughly speaking, we can say that a time averaged concentration in the street can be written as

$$c \approx \left\langle \frac{Q}{\sigma_w} \right\rangle \tag{11}$$

where $Q$ is the instantaneous emission of a single vehicle and $\sigma_w$ is the turbulence created by a single vehicle (we consider only the case of no, or very low, ambient wind). <> denotes time averaging. For the street traffic we can expect a strong correlation between $Q$ and $\sigma_w$, so the averaging will be over values that will not fluctuate so much. In a wind tunnel, $Q$ is constant, and the averaging will be only over a strongly fluctuating $1/\sigma_w$. What are the practical implications of this difference is not yet clear.