TRAFFIC SAFETY OF A SLOW VEHICLE

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Introduction

In accordance with the theory of traffic safety the vehicles (drivers) who drive at a speed different from the traffic flow speed get into traffic accidents more often than those vehicles (drivers) which drive at traffic flow speed. There is the more risk to get into traffic accidents the greater the difference in speed compared to traffic flow speed. Great difference between a slow vehicle (tractor, farm or forest machine, *etc*.) speed and traffic flow speed is the main risk factor for a slow vehicle which should be considered not only by the drivers of slow vehicles, but also by the drivers of fast vehicles.

The insecurity of a slow vehicle arises from the fact that in case of slow speed every manoeuvre, *eg* driving start, traffic lanes change, turns, passing, takes much time. A slow vehicle covers a short distance. A fast vehicle covers during the same time a significantly longer distance and its adaptation to the speed or stoppage of the fast vehicle in case of need requires a long distance. Inexperienced drivers of fast vehicles may not be able to evaluate the speed and distance of a slow vehicle properly and begin to slow down too late, having thus too little space for stopping the vehicle. To prevent road accidents, it is essential for the driver of a slow vehicle to make sure before any manoeuvre that he does not create a situation in which the driver of a fast vehicle will not be able to avoid a road accident. The driver of a slow vehicle has to indicate in good time before manoeuvre.

Keywords: *slow vehicle, fast vehicle, separation distance, stopping distance, adhesion factor, reaction time of driver.*

Material and Methods

When a slow vehicle drives on the road, it is significant for ensuring safety that the drivers of fast vehicles evaluate properly the safe distance when approaching the slow vehicle, slow down according to the decreasing distance and that the driver of the slow vehicle indicates timely before manoeuvre.

As we know, the value of safe separation distance in traffic flow is considered to be equal to half of speed number on urban road (if the unit of separation distance is *m* and unit of speed is *km/h*). On highway, the value of safe separation distance in traffic flow is considered to be equal to speed number. The recommendations are valid if the vehicles are driving at the same speed.

If a fast vehicle is approaching a slow vehicle, the safe separation distance is considered to be the distance which enables the fast vehicle to stop behind the slow vehicle, in case the latter is forced to stop unexpectedly and passing is impossible. Therefore, the safe separation distance is considered the smallest distance from the slow vehicle, at which the driver has to decide, whether the passing is possible or is it necessary to begin slowing down and adapting the speed to the decreasing distance. When approaching a slow vehicle, the distance is not constant, but decreases continuously. The stopping distance depends on speed, adhesion factor, efficiency of vehicle brake system, *etc*. To ensure safety, the fast driver approaching a slow vehicle can apply only one method – adapt the speed of his vehicle to the continuously decreasing distance. At the same time, the driver of the fast vehicle must be prepared for the worst, when the driver of the slow vehicle brakes unexpectedly.

Proceeding from the above-said, the safe separation distance may be expressed as follows (Figure 1):

$$S_{pv} = S_{kp} - S_{ap} + S_0, \quad (1)$$

where S_{kp} – stopping distance of fast vehicle, m;
S_{ap} – braking distance of slow vehicle, m;
S_0 – safety reserve, m.

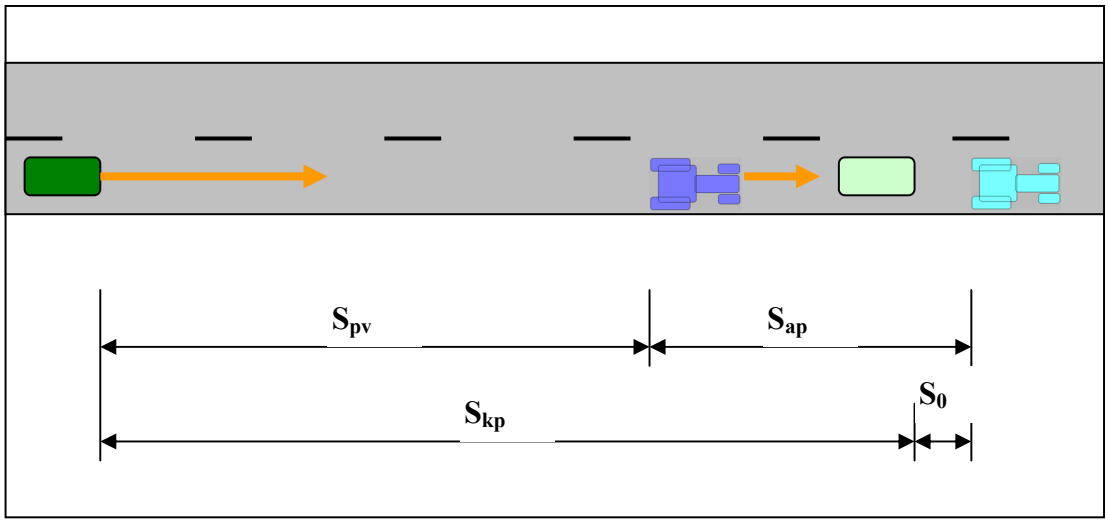

Figure 1. Safe separation distance
S_{pv} – safe separation distance, S_{ap} – braking distance of slow vehicle, S_{kp} – stopping distance of fast vehicle, S_0 – safety reserve

Expression to calculate the stopping distance of a fast vehicle:

$$S_{kp} = \left(t_j + t_{pk} + \frac{1}{2} t_{ak} \right) \cdot v_k + k_{ek} \frac{v_k^2}{2g\varphi_k}, \tag{2}$$

where t_j – reaction time of driver, s;
t_{pk} – application time of brakes, s;
t_{ak} – the time necessary to obtain the utmost possible deceleration, s;
v_k – speed of vehicle, m/s;
k_{ek} – vehicle brake system efficiency factor;
φ_k – road surface adhesion factor,
subscript *k* marks the fast vehicle and subscript *a* marks the slow vehicle.

The braking distance of a slow vehicle is shorter than the stopping distance by the driver's reaction distance:

$$S_{ap} = \left(t_{pa} + \frac{1}{2} t_{aa} \right) \cdot v_a + k_{ea} \frac{v_a^2}{2g\varphi_a}. \tag{3}$$

Taking into consideration expressions (1), (2) and (3) we obtain the expression for calculating the safe separation distance:

$$S_{pv} = \left(t_j + t_{pk} + \frac{1}{2} t_{ak} \right) \cdot v_k + k_{ek} \frac{v_k^2}{2g\varphi_k} + S_0 - \left(t_{pa} + \frac{1}{2} t_{aa} \right) \cdot v_a - k_{ea} \frac{v_a^2}{2g\varphi_a} \tag{4}$$

Using expression (4), the safe separation distance is calculated at following stipulations. A slow vehicle is approached by a fast vehicle on the highway at the speed of the fast vehicle equal to 90 km/h. The reaction time of the driver is taken equal to 0.8 s. It is assumed that the fast vehicle has disk brakes and brake force adjuster (t_{pk} = 0.1 s, k_{ek} = 1). The application time of the brakes of the slow vehicle is taken equal to 0.2 s. The safe separation distance is calculated for asphalt road surface (t_a = 0.5 s, φ_k = 0.9 ja φ_a = 0.8).

If it is not possible to pass the slow vehicle at once or if the situation is not definite, the driver of the fast vehicle has to slow down in time at sufficient distance. Using the above-given expressions, the safe speed of the fast vehicle is calculated depending on the separation distance and speed of the slow vehicle.

Results and Discussion

One significant circumstance influencing the safe separation distance is the speed of the slow vehicle. Slow vehicles may go on roads over ten times slower (4–40 km/h) than the traffic flow (90 km/h, presuming that the drivers of fast vehicles do not exceed the permissible speed). When the slow vehicle goes at 40 km/h (11 m/s), the driver of the fast vehicle who approaches the slow vehicle should begin slowing down no later than at the distance of 52 m from the slow vehicle, if passing is impossible (Figure 2). If the speed of the slow vehicle is equal to 30 km/h (8.3 m/s) (it is the most frequent speed for farm tractors), the driver of the fast vehicle should begin slowing down no later than at the distance of 57 m from the slow vehicle. When the slow vehicle goes very slowly (5 km/h or 1.4 m/s), the driver of the fast vehicle should begin slowing down at the distance of 66 m. Taking into consideration that it is quite difficult for the driver of the fast vehicle to estimate the speed of the slow vehicle, the driver of the fast vehicle should begin slowing down at a distance from the slow vehicle equal to 65 m, if passing is impossible or the situation is indistinct. If the driver exceeds the permissible speed, he must begin slowing down at a longer distance accordingly.

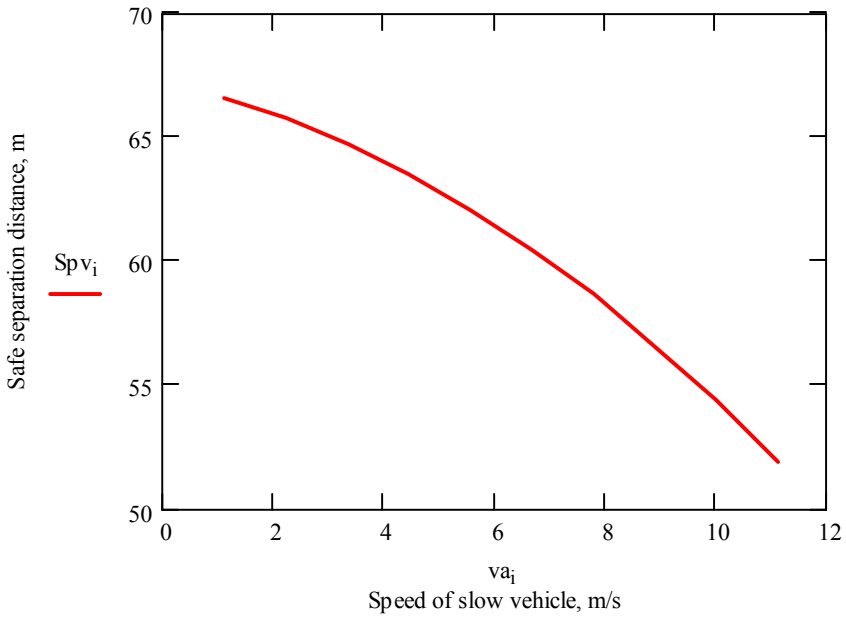

Figure 2. Dependence of safe separation distance on the speed of a slow vehicle

Safe separation distance is significantly affected not only by the speed of a slow vehicle but also by the speed of a fast vehicle. When the slow vehicle goes 20 km/h (5.5 m/s) and the fast vehicle runs also relatively slowly, for example 50 km/h (14 m/s) as it is permissible on urban road, safe separation distance is 25 m (Figure 3). The theory of traffic safety also recommends a separation distance equal to 25 m on urban road. When the fast vehicle runs on the highway at permissible speed (90 km/h or 25 m/s), safe separation distance is already 62 m and if driver exceeds the permissible speed, driving for example at 120 km/h (33.3 m/s), safe separation distance is already 99 m.

The above calculations and discussion are valid for dry clean asphalt road surface, having an adhesion factor equal to 0.9. On a more slippery road surface and in case of a smaller adhesion factor, safe separation distance becomes longer. When a slow vehicle runs 20 km/h and fast vehicle approaches it at 90 km/h, safe separation distance is equal to 64 m on dry clean asphalt road surface (adhesion factor $\varphi = 0.9$). On wet road surface ($\varphi = 0.7$–0.8), safe separation distance is equal to 70–74 m and on muddy or slimy surface ($\varphi = 0.6$ or less) safe separation distance is over 80 m in the above-mentioned case (Figure 4). On very slick road surface ($\varphi \leq 0.4$), safe separation distance is over 100 m at the given speeds.

It must be noted that the reaction time of the driver also has a certain effect on safe separation distance. The reaction time of a mindful driver is considered to be 0.8 s. Depending on various circumstances, the reaction time of the driver may vary in range of 0.5–1.2 s when braking the vehicle. The safe separation distance in this case is in range of 55–72 m if the slow vehicle goes 20 km/h and the speed of the fast vehicle is 90 km/h (Figure 5). Safe separation distance increases proportionally to the increasing of the driver's reaction time. The slow vehicle is particularly risky for a drunken or drugged driver whose reaction time is 2–3 s or more. At the mentioned reaction time, the driver must begin to slow down at separation distance equal to 100–120 m.

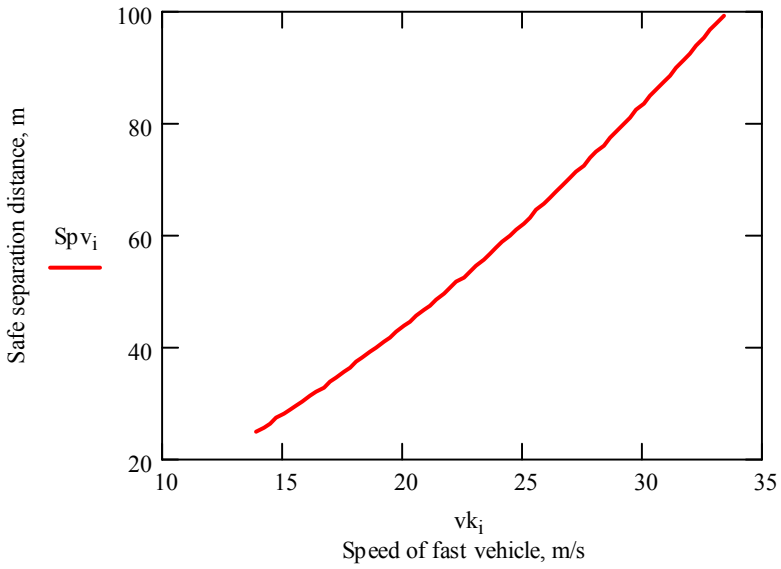

Figure 3. Dependence of safe separation distance on the speed of a fast vehicle

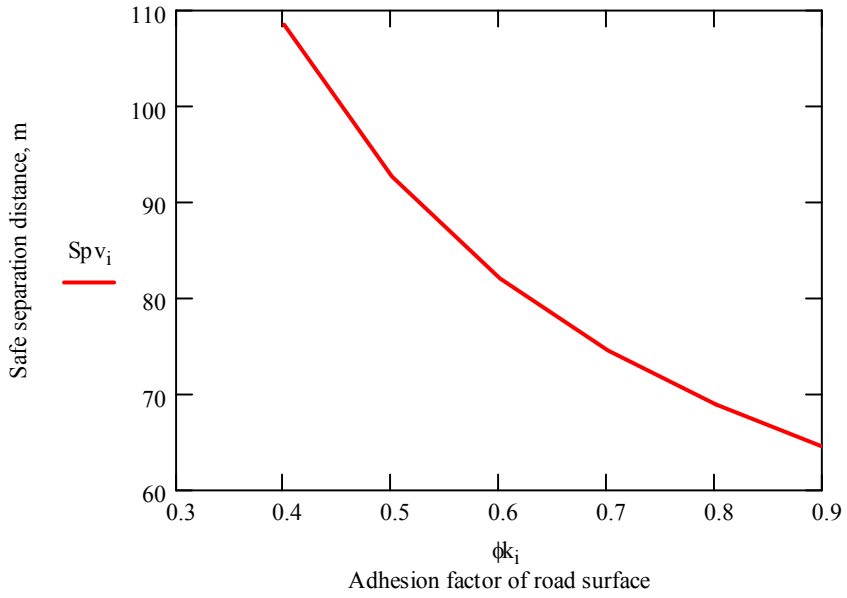

Figure 4. Dependence of safe separation distance on the adhesion factor of road surface

Approaching a slow vehicle, the driver of a fast vehicle has to slow down proportionally to the decreasing of the separation distance (Figure 6). Deceleration must be the more intensive the smaller the speed of the slow vehicle. If the slow vehicle goes 40 km/h (11 m/s), the driver of the fast vehicle has to slow down from 90 km/h (25 m/s) to 47 km/h (13 m/s) – 48% – when getting near the slow vehicle from the separation distance of 60m to the distance of 20 m.

If a slow vehicle goes 7 km/h (2 m/s), the driver of a fast vehicle has to slow down from 80 km/h (22 m/s) to 25 km/h (7 m/s) – 69% – when getting near the slow vehicle from the separation distance of 60 m to the distance of 20 m. Traffic regulations require that the driver must indicate at least 3 seconds before manoeuvre. If the driver of the slow vehicle indicates 3 seconds before manoeuvre on highway, he may put the driver of the fast vehicle in a situation, where the latter does not have enough space for safe stopping of vehicle, when the fast vehicle is closer than 60 m to the slow vehicle. The fast vehicle runs 75 m in 3 seconds at the speed of 90 km/h. The braking distance of the fast vehicle is equal to 40–45 m and the reaction distance of the driver is equal to 20–25 m at the speed of 90 km/h. 60–70 m of free space is necessary for stopping the vehicle at this speed. Late

and brief indication is risky, particularly before left turns and changing lanes on the left. The driver of a slow vehicle ought to indicate on the highway, when the fast vehicle is at the distance of 70–80m in the rear. The indication ought to be done 3–4 times longer than required by traffic regulations.

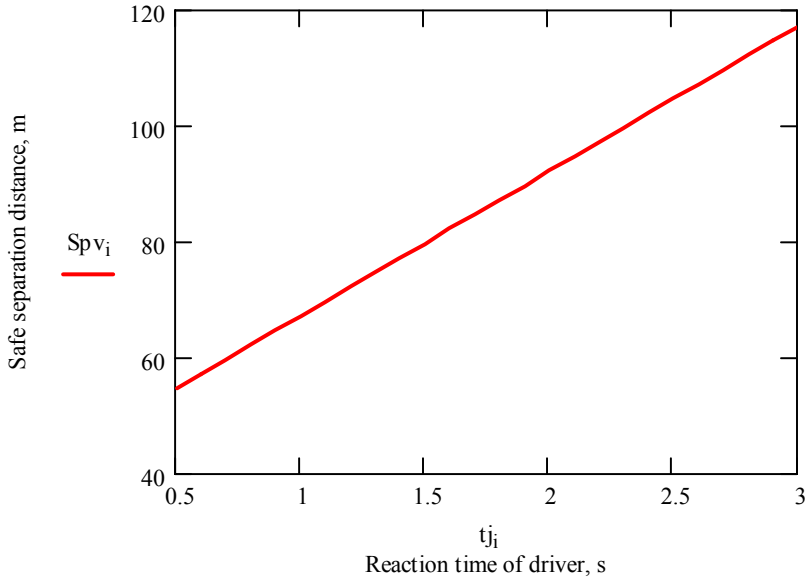

Figure 5. Dependence of safe separation distance on the reaction time of driver

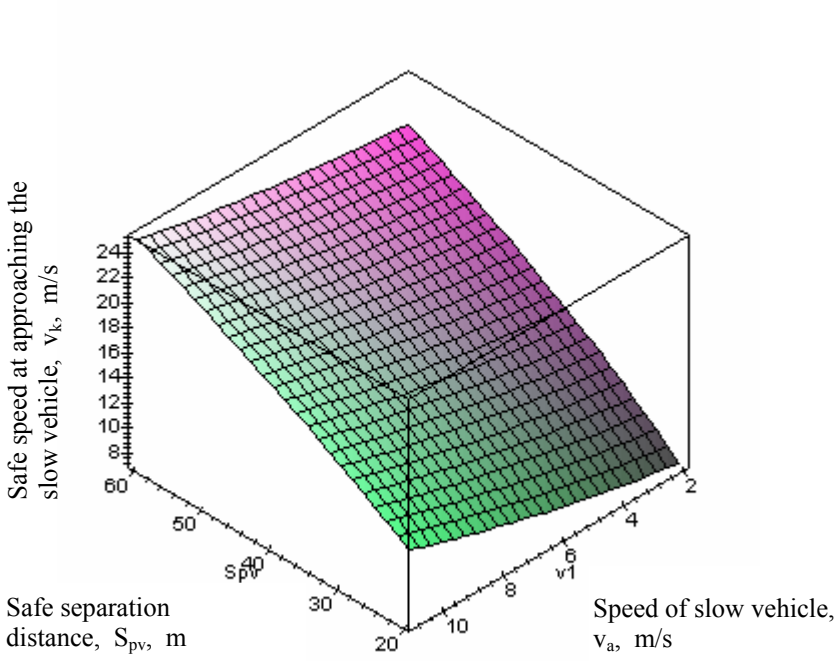

Figure 6. Dependence of safe speed at approaching the slow vehicle on safe separation distance and speed of the slow vehicle

Conclusions

Slow vehicles (tractor, farm or forest machine, *etc*.) which go on the roads significantly slower than the traffic flow, obstruct road traffic and become a source of hazard. This fact must be taken into consideration both by the drivers of slow vehicles and drivers of fast vehicles. For ensuring traffic safety, it is essential that the drivers be able to estimate the speed of vehicles and distances, when approaching a slow vehicle. In practice,

drivers estimate separation distance and speed of vehicles "by feeling", intuitively. It is necessary for the drivers to cognize safe separation distance and know the influencing factors.

The minimal distance from a slow vehicle (safe separation distance), at which the driver, approaching the slow vehicle, has to decide if it is possible to pass the slow vehicle at once or if he should start slowing down, has been studied in this paper. Dependence of safe separation distance upon the speeds of vehicles, on road adhesion factor and on the reaction time of the driver have also been studied.

Dependence of safe separation distance on the speeds of vehicles and on road surface adhesion factor is non-linear. Safe separation distance is 66–52 m in case of real speeds of vehicles (5–40 km/h for slow vehicles and 90 km/h for fast vehicles). As it is very difficult for the driver of a fast vehicle to estimate the exact speed of the slow vehicle, the driver of the fast vehicle must become observant with regard to the slow vehicle at the distance of 70 m and estimate the possibility of passing the slow vehicle.

The speed of the fast vehicle has greater impact than the speed of the slow vehicle on safe separation distance. In case of varying the speed of the fast vehicle in range 50–120 km/h, safe separation distance varies in range 20–100 m (speed of slow vehicle is equal to 20 km/h).

Road surface adhesion factor has as essential influence on safe separation distance as the speed of the fast vehicle. If on clean dry asphalt surface of the highway (speed of fast vehicle is 90 km/h and speed of slow vehicle is 20 km/h) safe separation distance is 64 m, then on wet surface of the highway, safe separation distance is 6–10 m longer, on muddy or slimy surface, safe separation distance is 15 m longer and on slippery road surface (adhesion factor $\varphi \leq 0.4$), safe separation distance is over 100 m at the given speeds (Figure 4).

Dependence of safe separation distance on the reaction time of the driver is linear. Safe separation distance is equal to 64 m when driving on the highway at given speeds and the reaction time of the driver is 0.8 s. Safe separation distance varies in range 55–72 m, if reaction time of driver varies in range 0.5–1.2 s. For a drunken or drugged driver whose reaction time is 2–3 s or more, safe separation distance is 100–120 m or more (Figure 5).

Approaching a slow vehicle, the driver of a fast vehicle must decrease the speed proportionally to the decrease of separation distance for ensuring traffic safety (Figure 6). At separation distance of 60 m, the safe speed is equal to 75–90 km/h, at distance of 40 m the safe speed is equal to 55–70 km/h and at the distance of 20 m the safe speed is 25–45 km/h, when the speed of a slow vehicle is 7–40 km/h.

The driver of a slow vehicle ought to indicate at least 6–10 s before left turn and changing to the left lanes.