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Deceleration to Safety Time (DST) - a useful figure to evaluate traffic safety? [1]

The traffic conflict technique (TCT) was developed in the fifties in the USA, taken over and modified by other countries. In the origin TCT - without technical equipment - traffic situations were watched by human observers, noted and analysed later on.

The hard criticism of the TCT in Germany led to the end of its systematically use and development in this country. The criticism was related to the bases of TCT and to its usefulness and subjectivity. In a discussion, the criticism of the TCT bases could have been rejected as not established. In addition, the usage and subjectivity could have been modified. But no discussion took place as well as no systematic modification.

Beside the conventional TCT, some techniques have been developed using the improved possibilities of computer technology and the methods of analysing traffic situations. Those techniques are based on objective measurements of physical parameters (distance, velocity, deceleration, direction). The most commonly used objective figures to evaluate traffic situations in relationship to its safety are Time To Collision (TTC) and Post Encroachment Time (PET).

The TTC describes the time distance to a collision of two road users if they keep their velocities and directions. The shorter the TTC the more dangerous is the situation. The TTC can be calculated over the time during the whole traffic situation. There are two values to evaluate the severity of a traffic conflict: The minimum TTC (TTC_{min}) which describes the most dangerous moment during a conflict as the moment of the smallest time distance of the involved road users. The TTC at the moment when an evasive action starts is called Time to Accident (TA). The differentiation between light and severe conflicts is usually defined as 1.5 seconds (TTC), or in relationship to a conflicting speed (TA).

The calculation of TTC needs a collision course which means, that the involved road users will be at the same place at the same time if they keep their velocity and direction. If the road users will miss

[1] This paper is based on a study made at the Transportation Department of the Kaiserslautern University, supported by the Stiftung Rheinland–Pfalz für Innovation (foundation for innovation of Rhineland-Palatinate)

each other by even a small time gap, there is no TTC to calculate, although the situation can not be declared as a safe one.

This insufficiency will be compensated by the Post Encroachment Time (PET). The PET is defined as the period of time from the moment when the first road user is leaving the conflict area[2] until the second road user reaches it. The size of this time gap is proportional to the unsafeness of the observed traffic situation. The border between light and severe conflicts is usually defined as 1,0 seconds. The PET can principally[3] be calculated during the whole situation. Usually, the last calculable PET (lastPET) is taken as figure to evaluate traffic safety. This is the moment, when the first road user leaves the conflict area.

Both figures (TTC and PET) consider "only" whether a collision occurs or not and how close. The necessary intensity of an evasive action to avoid a collision is not considered. Different situations can cause the same TTC, even if in one situation the driver only has to take the foot from the gas pedal and in an other situation an emergency breaking is necessary.

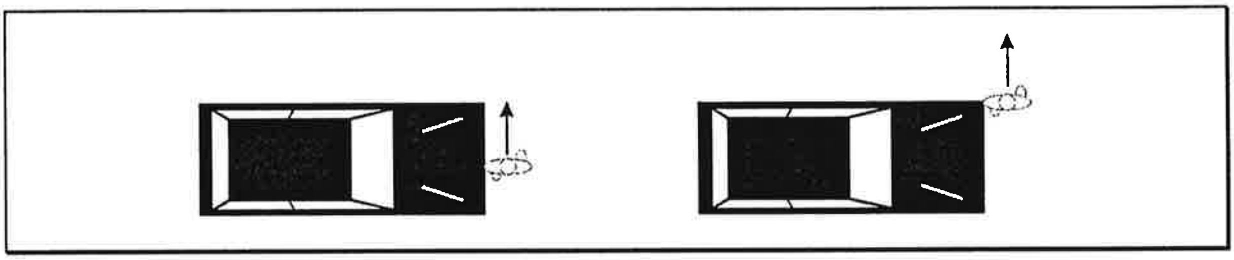

figure **Fel! Okänt växelargument.**: Identical TTCs at different prognosticated positions of a potential collision will require different evasive actions

During a traffic situation only TTC **or** PET is calculable at one moment. Obviously, the course of a safety describing figure has no "jumps" during a traffic situation. Using TTC and PET causes some gaps in the figures during the situation if there is no collision course at some moments.

The TTC describes the time to a critical situation (collision), PET relates to the result of a situation, regardless of the time until it occurrs. If e.g. the PET will amount to 0.5 seconds by unchanged velocities and directions, but the first road user will leave the conflict area in 5 seconds, the time distance of the second road user to the conflict area will be 5.5 seconds. This is time enough for an evasive action. The TTC of 0.5 means that a collision will occur in 0.5 seconds. There is no time for a controlled evasive action. In both cases the safety figure has a critical size without the same critical situation in reality.

[2] Assumption: both road users involved in an encounter keep their velocities and directions
[3] PET is only defined if there is no collision course

The analysis of video recorded conflicts during pedestrian crossings[4], TTC_{min} and lastPET sometimes showed critical (dangerous) values without any occurrence of a hazardous situation in reality.

These were the main reasons for an approach to evaluate traffic safety according to the necessary intensity to avoid a collision or to reach a safe time distance in the end of an encounter.

The necessary deceleration[5] to reach a last calculable PET ≥ 0 is defined as **Deceleration to Safety Time** ($DST_{t_{safety}}$). The index t_{safety} belongs to the chosen time distance (last PET) which has to be reached for a safe encounter.

The calculation of DST refers to the position of the first road user[6], as he leaves the conflict area. The second road user may reach this point not earlier than the first road user leaves it (PET=TTC=0 → DST_0).

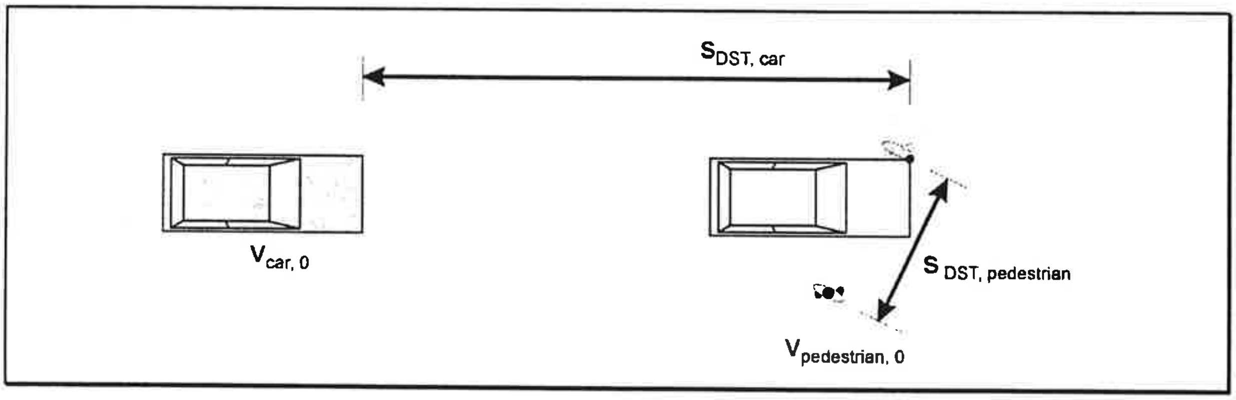

figure **Fel! Okänt växelargument.**: values to calculate DST shown on a pedestrian–car–conflict ($v_{pedestrian} = v_{pedestrian, 0}$ = constant, $v_{car} \neq$ constant)

For $v_{car} > 0$ and $v_{pedestrian} > 0$ is valid

$$t_{DST_0} = \frac{s_{DST,pedestrian}}{v_{pedestrian,0}} \overset{!}{=} \frac{s_{DST,car}}{v_{car,0}} \qquad v_{Kfz,0}, v_{Fg,0} > 0$$

$$s_{DST,car} = v_{car,0} \cdot t_{DST_0} + \frac{a \cdot t_{DST_0}^2}{2}$$

$$-a = \frac{2 \cdot (v_{car,0} \cdot t_{DST_0} - s_{DST,car})}{t_{DST_0}^2} = DST_0 \left[\frac{\mathrm{m}}{\mathrm{s}^2}\right]$$

For a required safety time distance of x seconds the DST can be calculated in general as

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[4] more than 6.000 recorded pedestrian crossings, 3.400 have been analysed by using PET and/or TTC
[5] taken as the main evasive action
[6] First road: The road user who reaches the conflict area first.

$$t_{DST_x} = \frac{s_{DST,ru_f}}{v_{ru_f,0}} + x = \frac{s_{DST,ru_s}}{v_{VTs,0}} + x \qquad v_{ru_f,0}, v_{ru_s,0} > 0$$

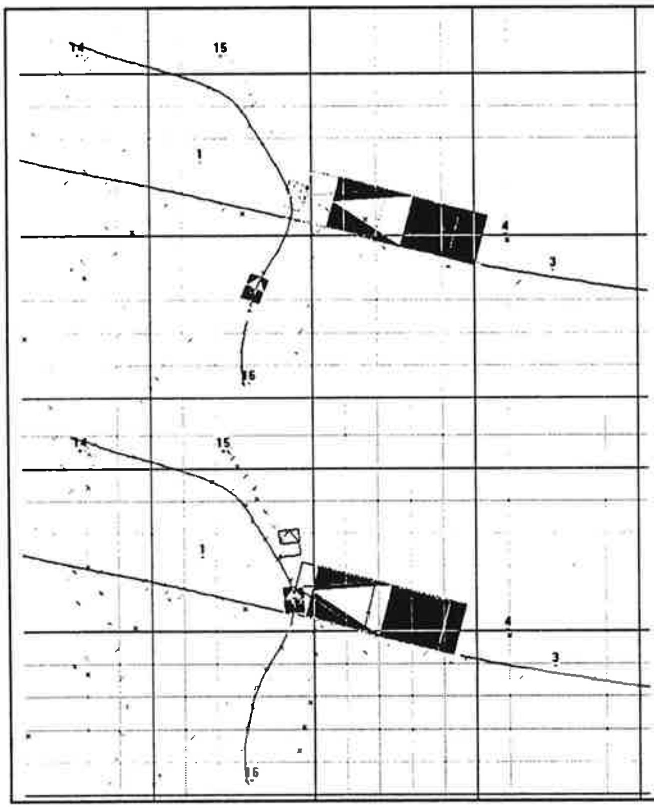
$$s_{DST,ru_s} = v_{ru_s,0} \cdot t_{DST_x} + \frac{a \cdot t_{DST_x}^2}{2}$$

$$-a = \frac{2 \cdot (v_{ru_s,0} \cdot t_{DST_x} - s_{DST,ru_s})}{t_{DST_x}^2} = DST_x \left[\frac{\mathrm{m}}{\mathrm{s}^2}\right]$$

ru_f : road user who reaches the conflict area first

ru_s : second road user

The use of DST shall be shown on the following example of a pedestrian crossing. The crossing person adapts his behaviour to the behaviour of the car driver. At first, he wants to cross behind the car and decelerates a little to give the right of way to the car driver. The car driver decelerates too, so the pedestrian crosses in front of the car.



The pedestrian decelerates to give the right of way to the car. In this time, a TTC can be calculated.
(TTC = 2.3 sec.)

The car decelerates too. The pedestrian crosses in front of the car.
(PET = 13.6 sec)

figure **Fel! Okänt växelargument.**: A pedestrian crossing visualised with an analysis tool. A filled box shows the actual position of a road user, an outlined box the predicted position by unchanged direction and velocity at TTC or PET. Both road users are slow.

The adapting behaviour is continuous shown by the DST_0 curve. The road users are moving on the border lastPET = 0. First there is a big PET, but when the pedestrian decelerates, it comes to a TTC less than 1.0 second. The DST (maximum 0.3 m/s²) detects no dangerous moment during the situation, the TTC_{min}, of course, does.

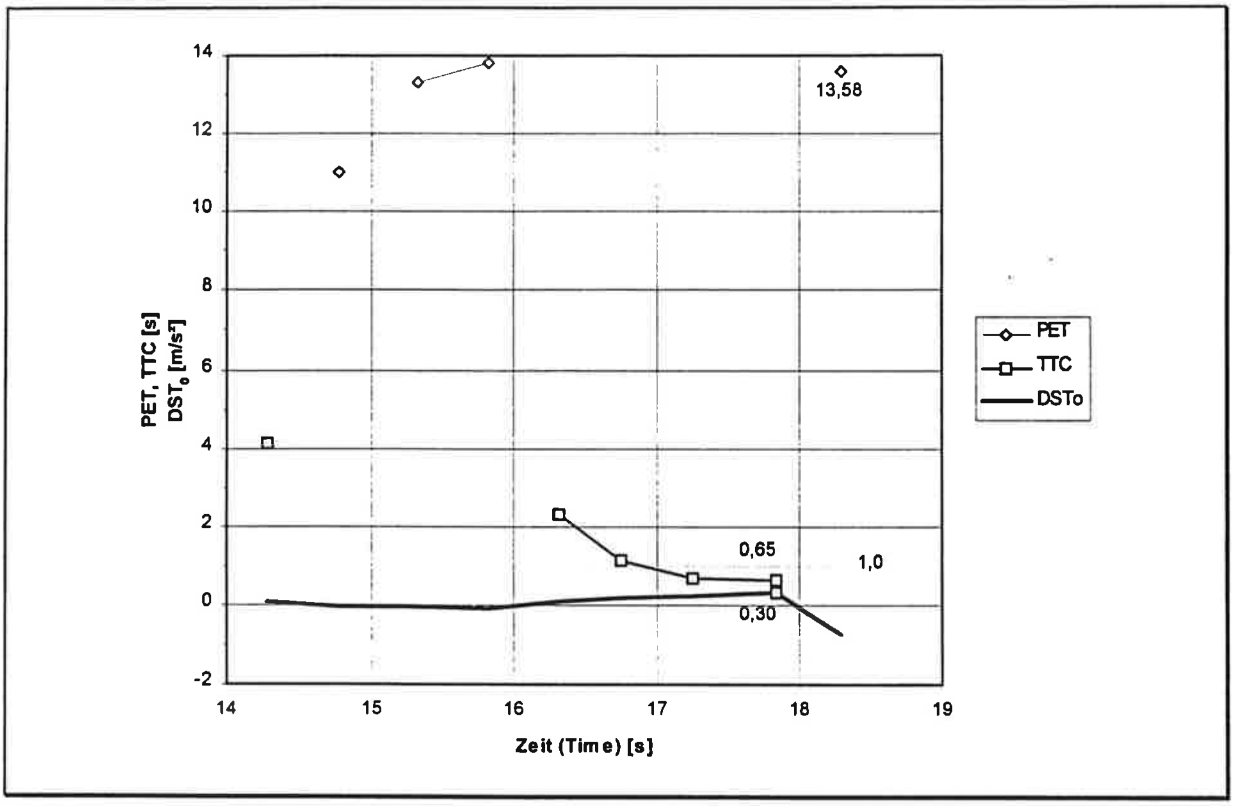


figure **Fel! Okänt växelargument.**: conflict values during a pedestrian crossing

The DST can be calculated for each moment of a traffic situation. It is positive (deceleration is necessary) if there is a collision course or a calculated PET < x, otherwise it is negative. The maximum DST gives an idea of the safety of a traffic situation.

The DST can be modified to various demands of safety (a safe situation maybe reached with a PET of 1 second → x=1) and various surrounding parameters (on a dry road are bigger decelerations possible than on a wet one).

DST gives the possibility to define the severity of a conflict following the conventional TCT:

$DST_X \leq 0$ m/s²:	Evasive action not necessary The predicted/reached safety time distance is bigger than *x*, an adaptation is not necessary.
$DST_0 < 1$ m/s²:	Adaptation necessary (interaction) The necessary evasive action is small, only a light adaptation has to be made.
$DST_0 < 2$ m/s²:	Reaction necessary (Conflict Level 1) The situation requires a noticeable deceleration of a road user. The situation is easy to control. There is time enough to consider other occurrences.
$DST_0 < 4$ m/s²:	Considerable reaction necessary (Conflict Level 2) The situation requires a considerable deceleration of one road user. The situation is controllable. Other occurrences can not be easy considered. (On a wet road this might be the maximum possible deceleration and is similar to an emergency breaking: Conflict Level 4)
$DST_0 < 6$ m/s²:	heavy reaction necessary (Conflict Level 3) The situation requires a heavy reaction of at least one road user involved in the conflict. The reaction is hardly controllable. Other traffic occurrences can not be considered.
$DST_0 \geq 6$ m/s²:	Emergency braking (Conflict Level 4) Uncontrollable reaction. Near miss accident.
Collision	

figure **Fel! Okänt växelargument.**: Suggested Definition of Conflict Levels under the use of DST according to the conventional TCT

A comparison of TTC, PET and DST in more than 3.400 situations was made by studying the safety of pedestrian crossings at different locations with different traffic parameters. The DST proved to be a reliable instrument to evaluate traffic situations in relationship to its safety.

For the analysis of the road user motion lines, their courses were detected as a polygon out of their positions in succeeded video pictures and rebuild as a mathematical function to calculate distance, velocity, direction and acceleration at each moment. This can be designated as a half automatically TCT. With the realisation of an automatically detection of road user positions out of video pictures by computers, a fully automatically TCT is possible.

Questions regarding the relationship between the number of light conflicts and its effects to traffic safety as well as how to handle the prediction of conflict values in curves (main base of TCT: direction unchanged) could not be answered. This has to be the aim of following studies.

Nevertheless, one result of the study was again, that video based Traffic Conflict Technique is a very helpful tool in traffic safety work - also in complement to accident analysis.