The Gipps model consists of two components: acceleration and deceleration. The first represents the intention of a vehicle to achieve certain desired speed, while the second reproduces the limitations imposed by the preceding vehicle when trying to drive at the desired speed. This model states that, the maximum speed at which a vehicle (n) can accelerate during a time period (t, t+T) is given by:

$$V_a(n,t+T) = V(n,t) + 2.5a(n)T\left(1 - \frac{V(n,t)}{V^*(n)}\right)\sqrt{0.025 + \frac{V(n,t)}{V^*(n)}} \quad (1)$$

where: V(n,t) is the speed of vehicle n at time t; V*(n) is the desired speed of the vehicle (n); a(n) is the maximum acceleration for vehicle n; T is the reaction time.

On the other hand, the maximum speed that the same vehicle (n) can reach during the same time interval (t, t+T), according to its own characteristics and the limitations imposed by the presence of the leader vehicle is:

$$V_b(n,t+T) = d(n)T + \sqrt{d(n)^2 T^2 - d(n)\left[2\{x(n-1,t) - s(n-1) - x(n,t)\} - V(n,t)T - \frac{V(n-1,t)^2}{d'(n-1)}\right]}$$

where: d(n) (< 0) is the maximum deceleration desired by vehicle n; x(n,t) is position of vehicle n at time t; x(n-1,t) is position of preceding vehicle (n-1) at time t; s(n-1) is the effective length of vehicle (n-1); d'(n-1) is an estimation of vehicle (n-1) desired deceleration. The final speed for vehicle n during time interval (t, t+T) is the minimum of those previously defined speeds:

$$V(n,t+T) = min\left\{ V_a(n,t+T), V_b(n,t+T) \right\}$$

The position of vehicle n inside the current lane is updated by taking the speed into the movement equation:

$$x(n,t+T) = x(n,t) + V(n,t+T)T$$

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2.1.1 Speed calculation

The first improvement is related to the vehicle speed $V^*(n)$ used in equation (1). In AIMSUN implementation $V^*(n)$ is the desired speed of vehicle n for the current section. In car-following a leading vehicle, attempts to drive to its maximum desired speed. Three parameters are used to calculate the maximum speed of leading vehicle *n* while driving on a particular section or turning:

1. Maximum desired speed of *n*: $v_{\max}(n)$. This is a vehicle parameter.

   Speed acceptance of *n*: $\theta(n)$ This is a vehicle parameter measuring the driver's degree of compliance of the speed limits on the section. $\theta(n)=1$, represents the perfect compliance. $\theta(n)<1$, a driver driving below the speed limits, and $\theta(n)>1$, faster than the speed limits. $\theta(n)$ is a vehicle parameter that in AIMSUN can be sampled from a probability distribution, when such information is available, modeling implicitly in that way the aggressivity of the drivers.

2. Speed limit in section or turning s: $S_{\lim nt}(s)$. This is a section parameter.

   The actual speed limit for a vehicle *n* on a section or turning *s*, $S_{\lim nt}(n,s)$, is given by:

   $$S_{\lim nt}(n,s) = S_{\lim nt}(s) \cdot \theta(n)$$

   The maximum desired speed of vehicle *n* on a section or turning *s*, $v_{\max}(n,s)$ is:

   $$v_{\max}(n,s) = MIN\left[s_{\lim nt}(n,s), v_{\max}(n)\right]$$

   Thus th elocal maximum desired speed $v_{\max}(n,s)$ equals the desired speed V*(n) in Eq. (1).

2.1.2 Influence of adjacent lanes

When the leading vehicle is driving along a section, the AIMSUN car-following model takes into account the potential influence of certain number of vehicles (*Nvehicles*) driving slower in the adjacent right-side lane –or left-side lane, when driving on the left–. The model calculates first the mean speed for *Nvehicles* driving downstream of the vehicle in the adjacent slower lane (*MeanSpeedVehiclesDown)*. Only vehicles within a certain distance (*MaximumDistance*) from the current vehicle are taken into account. We distinguish two cases: 1) the adjacent lane is an on-ramp, or acceleration lane, and 2) the adjacent lane is any other type of lane. Apart from *Nvehicles* and *MaximumDistance* parameters, the user can define two additional parameters, *MaximumSpeedDifference and MaximumSpeedDifferenceOnRamp*. Then, the final desired speed of a vehicle on a section is given from the following logic:

if (the adjacent slower lane is an On-ramp)
{MaximumSpeed = *MeanSpeedVehiclesDown* + *MaximumSpeedDifferenceOnRamp*}
else {MaximumSpeed = MeanSpeedVehiclesDown + MaximumSpeedDifference}
DesiredSpeed = Minimum ($v_{\max}(n,s), \theta(n)$ * MaximumSpeed)

This procedure ensures that the differences of speeds between two adjacent lanes will always be lower than *MaximumSpeedDifference* or *MaximumSpeedDifferenceOnRamp*, depending on the case.

Lane changing model

The lane change model in AIMSUN can also be considered as a further evolution of the Gipps lane change model (Gipps, 1986). Lane change is modeled as a decision process analyzing the necessity of the lane change (as in the case of turning maneuvers determined by the route), the desirability of the lane change (as for example to reach the desired speed when the leader vehicle is slower), and the feasibility conditions for the lane change that are also local, depending on the location of the vehicle on the road network. The lane-changing model is a decision model that approximates the driver's behavior as follows:

Each time a vehicle has to be updated the model draws up the question*: Is it necessary to change lanes?* The answer to this question depends on several factors: the turning feasibility at current lane, the distance to next turning and the traffic conditions in the current lane. The traffic conditions are measured in terms of speed and queue lengths. When a vehicle is driving slower than he wishes, he tries to overtake the preceding vehicle. On the other hand, when he is traveling fast enough, he tends to go back to the slower lane.

If the answer to the previous question is affirmative, to succeed in the lane changing two more questions have to be answered:

a) *Is it desirable to change lanes?* This requires checking if there will be any improvement in the traffic conditions for the driver as a result of the lane changing. This improvement is measured in terms of speed and distance. If the speed in the future lane is faster (i.e. a user specified threshold is exceeded) than the current lane or if the queue is shorter than a threshold, then it is desirable to change lanes.

b) *Is it possible to change lanes?* This requires verifying if there is a sufficient gap to do the lane change with complete safety. For this purpose, we calculate both the braking imposed by the next downstream vehicle to the changing vehicle and the braking applied by the changing vehicle to the future upstream vehicle. If both braking ratios are acceptable then lane changing is possible.

In order to achieve a more accurate representation of the driver's behavior in the lane changing decision process, three different zones inside a section are considered, each one corresponding to a different lane changing motivation. The distance up to the end of the section characterizes these zones and which is the next turning point. The figure 5 depicts the structure of these zones that are defined as follows:

- **Zone 1**: This is the farthest from the next turning point. The lane changing decisions are governed by the traffic conditions of the lanes involved; the feasibility of the next desired turning movement is not yet taken into account. To measure the improvement that the driver will get on changing lanes several parameters are considered: the desired speed of the driver, speed and distance of the current preceding vehicle and speed and distance of the future preceding vehicle.

- **Zone 2**: This is the intermediate zone. Mainly it is the desired turning lane that affects the lane changing decision. Vehicles who are not driving on a valid lane (i.e. a lane where the desired turning movement can be done) tend to get closer to the correct side of the road where the turn is allowed. In this zone vehicles look for a gap and may try to accept it without affecting the behavior of vehicles in the adjacent lanes.

- **Zone 3**: This is the nearest to the next turning point. Vehicles are forced to reach their desired turning lanes, reducing the speed if necessary and even coming to a complete stop in order to make the lane change possible. Also, vehicles in the adjacent lane can modify their behavior in order to allow a gap big enough for the lane-changing vehicle

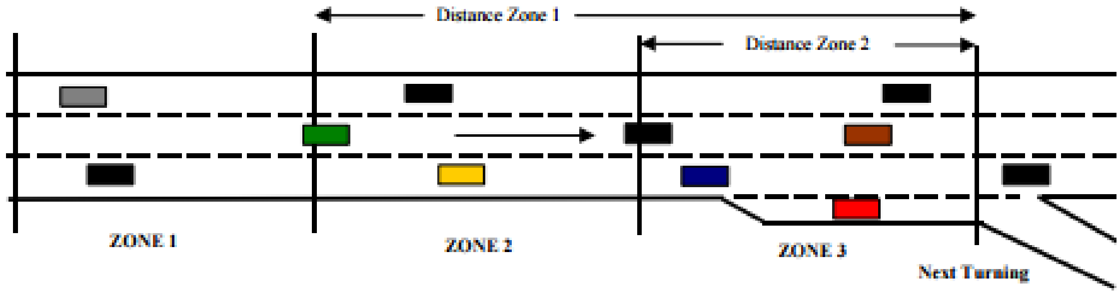


Figure 5: Lane Changing Zones

Lane changing zones are defined by two parameters, Distance to Zone 1 and Distance to Zone 2. These parameters are defined in time (seconds) and they are converted into distance whenever it is required for each vehicle at each section using the Vehicle Desired Speed at a Section. This means that these distances are then local parameters their value depending on the current traffic conditions on the section. When a vehicle crosses from zone 1 to zone 2 there is a change in the vehicle's behavior, as now it becomes relevant the next turn. Also the crossing from zone 2 to zone 3 produces a change in the behavioral rules of the vehicles, as now reaching the turning lane becomes urgent. In order to distribute these changes of behavior along a longer distance a greater variability is given to the Lane Changing Zones. These zones are calculated particularly for each vehicle according to the following equation:

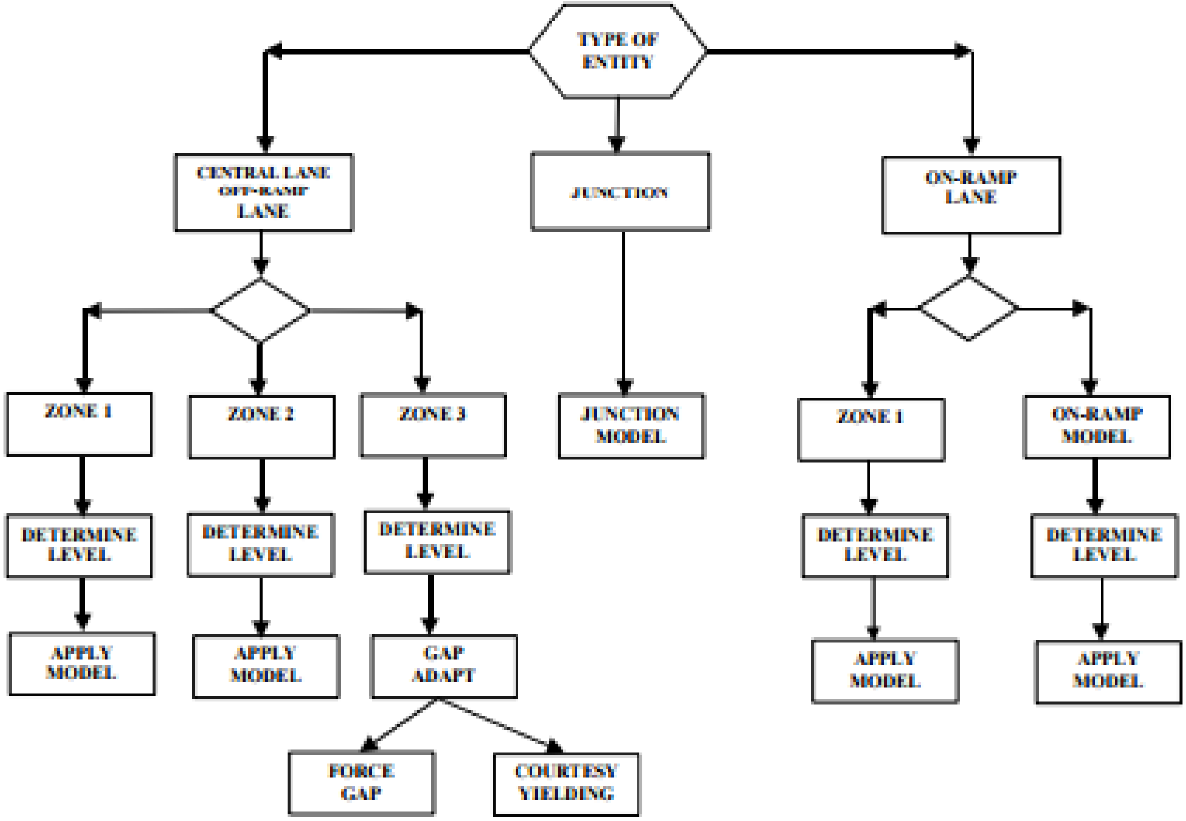
Distance Zone n for vehicle ***v*** in section ***s*** (in meters) =
Distance Zone n (in seconds) * Speed Limit of Section ***s*** * Vehicle ***v*** Coefficient
Vehicle ***v*** Coefficient = Speed Limit of Section ***s*** / Desired speed of Vehicle ***v*** in section ***s***

This algorithm ensures that for vehicles whose desired speed is slower than the speed limit the lane changing zones will be longer than for vehicles whose desired speed is greater than the speed limit. It means for instance that a heavy truck will try to reach the appropriate turning lane earlier than a speed car.

Look Ahead

When traffic conditions are very congested it may happen that some vehicles cannot reach the appropriated turning lane and consequently miss the next turn. This situation could appear either in urban networks where there are short sections or in freeways where weaving sections may be relatively short. It gets worst as the sections get more congested. Tuning some modeling parameters such as lane changing zone distances, simulation step, acceleration rates etc., could improve the behavior in order to minimize the number of lost vehicles. Also using polysections in modeling the geometry instead of sections, when feasible, to model streets or weaving areas might help to improve the situation, but it was not enough. To override these drawbacks a major improvement has been done in the lane change model consisting in modeling a Look Ahead process. The objective is to provide vehicles with the knowledge of various next turning movements and not only one, so they will be able to make decisions not only based on the immediate next turning movement, but on a set of next turning movements. The Look Ahead consists of four steps:

1. At any time, each vehicle knows the next two turning movements, so the lane changing decisions are influenced by two consecutive turns.
2. The lane changing zones 2 and 3 of any section is extended back beyond the limits of the section, therefore affecting the upstream sections.
3. The next turning movement also influences the turning maneuvers so the selection of destination lane is done based also on the next turn.
4. A greater variability is given to the Lane Changing Zones in order to distribute the lane changing maneuvers along a longer distance.



The Lane-Changing decision process

The whole lane change process is modeled formally as a decision tree model whose logic structure is depicted in the diagram of figure 6. The process identifies the type of entity (central lane, off-ramp lane, junction, on-ramp etc.) in which the maneuver is going to be done, next determines how the zone modeling should be applied. The current traffic conditions are analyzed and the level at which the lane change can be performed is determined, and then the corresponding model is applied, this also includes the specific modeling of lane change prohibitions and overtaking maneuvers, as well as specific Gap Acceptance models for each situation. For further details see AIMSUN User's Manual (2002).

Gap acceptance models in AIMSUN

Two typical situations in which gap acceptance should be applied are:

- In lane changing, and
- To model give way behaviour

Gap Acceptance Model in Lane changing

To answer the question *"Is it possible to change lanes?"* AIMSUN applies the following algorithm to check whether the gap is acceptable or not.

```
Get downstream and upstream vehicles in target lane
Calculate gap between downstream and upstream vehicles: TargetGap
if ((TargetGap > VehicleLengh) & (it is aligned)) then
   Calculate the distance between vehicle and downstream vehicle in target lane: DistanceDown
   Calculate the speed imposed by downstream vehicle to vehicle, according to Gipps
                                                   Car-following Model: ImposedDownSpeed
   if (ImposedDownSpeed is acceptable by vehicle, according to the deceleration rate) then
      Calculate the distance between upstream vehicle in target lane and vehicle: DistanceUp
      Calculate the speed imposed by vehicle to upstream vehicle, according to Gipps
                                                   Car-following Model: ImposedUpSpeed
      if (ImposedUpSpeed is acceptable by upstream vehicle, according to the deceleration
        rate) then
         Lane Change is Feasible
         CarryOutLaneChange
      else
         The gap is not acceptable because of the upstream vehicle
      endif
   else
      The gap is not acceptable because of the downstream vehicle
   endif
else
   There is no gap aligned with the vehicle
endif
```

Gap Acceptance Model in give way

The Gap-Acceptance model used to model give way behaviour determines whether a lower priority vehicle approaching a junction can or cannot cross depending on the circumstances of higher priority vehicles (position and speed). This model takes into account the distance of vehicles from the hypothetical collision point, their speeds and their acceleration rates. It then determines the time needed by the vehicles to clear the junction and produces a decision to cross or not which is also a function of the level of risk for each driver. Several vehicle parameters may influence the behaviour of the gap-acceptance model: acceleration rate, desired speed, speed acceptance and maximum give-way time. Other parameters, such as visibility distance at the junction and turning speed, which are related to the section, may also have an effect. Among these, the acceleration rate, the maximum give-way time and the visibility distance at junctions are the most important. The acceleration rate gives the acceleration capability of the vehicle and therefore has a direct influence on the required safety gap. The maximum give-way time is used to determine when a driver starts to get impatient if he/she cannot find a gap. When the driver has been waiting for more than this time, it reduces the safety margin (normally two simulation steps) by half (only one step). The following algorithm is applied in order to determine whether a vehicle approaching a give-way sign can cross or not (see Figure 7):

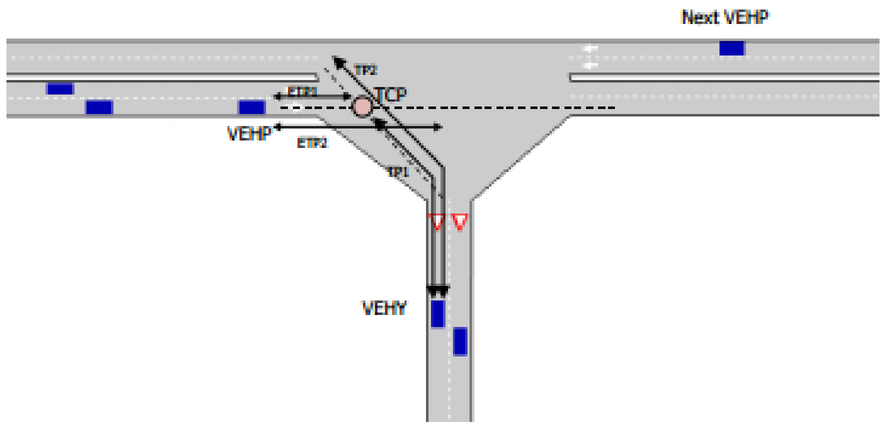


Figure 7

Given a vehicle (VEHY) approaching a Yield (Give Way) junction,

Obtain the closest higher priority vehicle (VEHP),
Determine the Theoretical Collision Point (TCP),
Calculate the time (TP1) needed by VEHY to reach TCP,
Calculate the estimated time (ETP1) needed by VEHP to reach TCP,
Calculate the time (TP2) needed by VEHY to cross TCP,
Calculate the estimated time (ETP2) needed by VEHP to clear the junction,

If TP2 (plus a safety margin) is less than ETP1, vehicle VEHY has enough time to cross, therefore it will accelerate and cross,

Else, if ETP2 (plus a safety margin) is less than TP1, vehicle VEHP will have already crossed TCP when VEHY reaches it, then search for the next closest vehicle with a higher approach, Next VEHP and go to step 2.

Else, vehicle VEHY must give way, decelerating and stopping if necessary.