INTERSECTION DECISION SUPPORT SYSTEM USING GAME THEORY ALGORITHM

Dedicated Short Range Communications (DSRC)

Game Theory

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INTRODUCTION

Many of the intersections in the US are simple at-grade with two-way stop sign control, and highway engineers can be faced with a dilemma when the crash experience at one of these intersections indicates that an intervention is required. Consequently, an urgent need for innovative ideas for preventing crashes and reducing delay is needed.

At Stop sign controlled, the drivers face the dilemma of accepting or rejecting the offered gap to merge with the main flow. Gap acceptance/rejection behavior is considered one of the major factors that affect the capacity, saturation flow rate and collision risk at intersections. A gap is defined as the elapsed-time interval between arrivals of successive vehicles in the opposing flow at a specified reference point in the intersection area. The minimum gap that a driver is willing to accept is generally called the critical gap. One of the factors that affect the capacity, saturation flow rate and safety at signalized and non-signalized intersections is gap acceptance behavior. Gap acceptance is defined as the process that occurs when a traffic stream (known as the opposed flow) has to cross another traffic stream (known as the opposing flow) or merge with the opposing flow.

The minimum gap that a driver is willing to accept is generally called the critical gap. The Highway Capacity Manual (HCM 2000) [1] defines the critical gap as the “minimum time interval between the front bumpers of two successive vehicles in the major traffic stream that will allow the entry of one minor street vehicle.” Since the critical gap of a driver cannot be measured directly, censored observations (i.e., accepted and rejected gaps) are used to compute critical gaps, as will be described later. For more than three decades research efforts have attempted to model driver gap acceptance behavior, using either deterministic or probabilistic methods. The deterministic critical values are treated as a single threshold for accepting or rejecting gaps.

Driver gap acceptance behavior traffic situation is considered a decision making traffic process and sometimes the driver could misjudge the offered gap size which could lead him to crash. Consequently, it should be introduced an intelligent system for driver guidance and assistance for preventing crashes; especially during adverse weather conditions: Intersection Decision Support (IDS). The proposed decision support system will depend on vehicle to vehicle (V2V) communication using game theory algorithm as an innovative approach for driver assistance.

Proposed Critical Gap Model

Driver gap acceptance behavior entails estimating the duration of time it would take the subject vehicle to traverse a conflict point and avoid collision with an opposing vehicle. Typically, the driver requires some additional buffer of safety to ensure that no collision occurs. Consequently, the modeling of driver gap acceptance behavior requires the modeling of driver acceleration behavior and the additional buffer of safety the driver requires to accept a gap.
Mathematical representations of the gap acceptance process are an important component of traffic simulation software. In an attempt to provide a more realistic representation of this behavior, these mathematical descriptions have become more complex by including driver behavior parameters, such as ‘impatience’ or ‘aggressiveness’ associated with various parameters. Hence, the process is difficult because drivers do not know the number and size of gaps that will be offered to them a priori. The variables affecting the gap acceptance/rejection decision may be difficult to identify and the driver choice could be risky.

It can be stated that previous research has made simplifying assumptions and failed to capture the impact of various factors on gap acceptance behavior. This research effort is a modest attempt to address some of these issues. The factors that are studied include:

1. Driver aggressiveness and impatience as a function of the level of acceleration used by the driver and the buffer of safety that driver is willing to accept in order to avoid a conflict with a conflicting opposing vehicle;
2. The vehicle characteristics (e.g. vehicle power, mass and engine capacity);
3. Weather impact (rain intensity) and roadway surface condition (dry or wet) effect on gap acceptance behavior;

GAP ACCEPTANCE/REJECTION SCENARIO

The proposed modeling approach captures the psychological deliberation of the driver in addition to the physical constraints imposed by the vehicle. In addition, the model captures the interface between the vehicle tires and the roadway surface. The proposed model considers the driver specific critical gap (the minimum gap a driver is willing to accept) for each driver, is the summation of the travel time to reach the conflict point, the time needed to clear the length of the vehicle and an additional buffer of safety time as

$$t_c = t_r + t_T + t_L + t_S$$  \hspace{1cm} (1)

Where; $t_c$ is the critical gap duration for a specific driver, $t_T$ is the reaction time for the driver, $t_T$ is the time required to travel to conflict point, $t_L$ is the time required to clear the length of the vehicle the conflict zone and $t_S$ is the duration of the buffer of safety to avoid a conflict with an oncoming vehicle. For stop sign controlled intersection, the gap acceptance/rejection scenario could be summarized in Figure 1.
The vehicle number (2) represents the coming vehicle from a minor road and will be waiting at the stop sign for appropriate gap to merge with the main stream traffic flow. The offered gap for vehicle (2) is the gap between the first opposing vehicle (1) and the second opposing vehicle (3). In order to accept the offered gap, it should be equal or more to the critical gap value for the driver in vehicle (2) that explained previously. Each dashed vehicle presents the position after \( \Delta t \) (from \( t_1 \) to \( t_2 \)). Figure 2 illustrates the trajectories (time-space diagram) for vehicle 1 and vehicle 2 (the upper graph and the lower graph, respectively).

For vehicle 1 (Figure 2a), it has two optional trajectories: (1) Constant speed trajectory and (2) Decelerated trajectory. The first trajectory indicates that the vehicle 1 crossed the intersection with the constant speed and reached the point \([X4]\) at time \([t_2']\). The second trajectory indicates that the vehicle 1 decelerated at the beginning of the intersection to provide the minimum acceptable gap, i.e. critical gap, “\( t_c \)” for vehicle 2. Consequently, vehicle 1 reached point \([X1]\) at time \([t_1]\) instead of \([t_1']\) and that will lead to a delay with value “delay1”.

For vehicle 2 (Figure 2b), it has three possible trajectories: (1) Non-stop trajectory, (2) Accepted gap trajectory and (3) Rejected gap trajectory. The first trajectory is a virtual trajectory for a vehicle coming from a minor approach with stop sign controlled and indicates that vehicle2 did not stop and merged with the major flow directly.
The veh (2) did not stop at the intersection.

The veh (2) accepted the offered gap.

The veh (2) rejected the offered gap.

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Figure 2: Time space diagram for vehicle 1 (main approach) and vehicle 2 (minor approach)

The second trajectory indicates the case when vehicle 2 accepted the offered gap “greater or equal to $t_c$”. Therefore, the total delay in that case for vehicle 2 (delay2) is equal to: time needed to decelerate at the stop sign ($t_{dec}$), stopping time ($t_{stop}$), reaction time ($t_R$), and time needed to accelerate ($t_{acc}$) and reach conflict point [X4] at time [t2] to merge with the main flow. The third trajectory is the case when vehicle 2 rejects the offered gap.
gap; consequently, the total delay will increase by the amount of the offered gap and will be equal to \((\text{delay}_2')\).

**INTERSECTION DECISION SUPPORT “IDS”**

There are several traditional countermeasures for reducing crossing path crashes at intersections controlled by two-way stop signs. Warning signs are some of the ways to increase drivers’ awareness of the stop signs ahead and flashing lights on signs. While possibly reducing the likelihood of running the stop sign, such countermeasures would not help drivers entering from the minor roadway in choosing an appropriate gap to enter the intersection. The integration of road and vehicle systems, so-called cooperative (assistance) systems, offers new possibilities to improve traffic safety, traffic throughput and quality of life [2]. One of the intelligent applications for driver assistance is the Intersection Decision Support “IDS”.

With the premise that the driver’s attention has been captured, the IDS system will provide a driver timely, relevant information regarding unsafe conditions. In addition, the information that a vehicle was about to violate the stop sign could also be provided to the vehicle proceeding along the major roadway. The value of such information for avoiding conflict with the violating vehicle would have to be weighed against the risk of increasing rear end or other crashes on a busy roadway.

The trade-off study for wireless communications technologies that could be implemented in the IDS application were compared and analyzed in Virginia Tech Transportation Institute report study (2006) [3]. It was investigated the feasibility of many wireless communications technologies for intersection-based safety systems. At the end, the Dedicated Short Range Communications (DSRC) was the found the most recommended way of communication between vehicles for safety application.

For drivers on the minor roadway who have stopped and who are about to enter onto the major roadway, the major task is selecting an adequate gap and then successfully executing the entrance to the roadway. A critical task is to determine what gaps are sufficient and which are not. Consequently, the primary concern of the report is to understand how drivers make their decisions with regards to accepting or rejecting a given gap and which factors affect these decisions. Therefore, it is proposed to use “Game theory” in evaluating the different choices for each driver and helping to take the appropriate decision as will be explained in the following section.

**GAME THEORY OVERVIEW**

A game is simply defined as a conflict in interest among \(n\) individuals or groups (players). There exists a set of rules that define the terms of exchange of information and pieces, the conditions under which the game begins, and the possible legal exchanges in particular conditions. The entirety of the game is defined by all the moves to that point, leading to an outcome. The game theory has been applied in many engineering, economics and biological fields. However, the cooperation of intersection decision support with game theory algorithm is considered an innovative idea in transportation
engineering application. The gap acceptance/rejection scenario could be treated as a game between vehicle1 and vehicle2 for the intersection decision support system as will be illustrated in this section.

*Game theory classifications*

Each game could be classified one of the following three categories: Game of Skill, Game of Chance or Game of Strategy[4] as shown in Figure 3. Game of skill is the game of one player and do not involve any other player. The solitary player in that kind of games knows for certain what the outcome of any choice will be. Game of Chance is the game of one player against nature where the single player is not making decisions under the condition of certainty. Game of chance either involves risk, where the probability of nature’s response is known; or involves uncertainty where the probability of nature’s response is not known. Example of game of chance could be throwing a die or playing golf. Game of strategy is the game of two or more players where each player is trying to choose the best strategy for him in order to maximize the total benefit (or pay-off). A player’s strategy is a complete set of instructions that lead the player for an action given a set of information. A game of strategy could be played by two players or multi-players. This kind of games could be mainly divided into two categories: Cooperative game or Non-cooperative game.

For cooperative game, the pay-off for each potential group can obtain by the coalitional of its members (or players). The cooperative games are interesting only for their decision-making process, since they are games without conflict in which the players have coinciding interests. The challenge of the cooperative game is to allocate the pay-off (benefit) among the players in some fairway. On the other hand, for the non-cooperative game (or zero sum game), each player is looking for his own pay-off and the game is strictly competitive in that one player gains, the other loses. Decision-makers often have to choose independently from among alternative courses of action. Communication may be impossible or undesirable and there may be no prospect of forming a coalition.

The mixed motive games have more realistic solution than those arising from completely cooperative games or non-cooperative games. In many of transportation situation, the drivers could be treated as players participating firstly in a non-cooperative game then turn to cooperative game. At stop sign control intersection, the drivers could be considered as players participating in gap acceptance/rejection game that categorized as a mixed-motive game.
Elements of the game (Describing a game):

Any game usually consists of the following elements [5]: Players, actions, information, strategies, pay-offs, outcomes and equilibrium as will be described in details in the following paragraphs.

Players are the individuals who make decisions. Each player’s goal is to maximize his utility by choice of actions. Actions are the choices of each player can make and it could be one or a set of actions for a player to choose between them. The player’s strategy is a rule that tells him which action to choose at each instant of the game given his information set. Furthermore, Pay-off is the expected benefit or utility that he player will receive after all players have picked their strategies and the game has been played. Outcome is a set of interesting elements that the modeler picks from the values of actions, pay-offs and other variables after the game is played out.
For the equilibrium, once the players have settled on strategies that neither player has incentive to deviate is called the Nash equilibrium (named after John Forbes Nash). Alternatively, the player’s dominant strategy is defined as the strictly best response for a player even to very stupid actions by other players [5]. Some of literature defines simply the equilibrium as the best decision by the player given that the other player already chose his decision. Consequently, every dominant strategy is Nash equilibrium, but not every Nash equilibrium is a dominant strategy.

**Gap Acceptance/Rejection Game Structure:**

For gap acceptance/rejection (acc/rej) traffic scenario, the interaction between the vehicle of the major approach (vehicle 1) and the vehicle of the minor approach (vehicle 2) could be treated as a game and the drivers are the players. For the gap acc/rej situation, the driver of the main flow (vehicle 1) is facing the dilemma to cooperate with the minor approach vehicle (vehicle 2) or not. The cooperation of vehicle 1 could be by decelerating to offer vehicle 2 a larger gap in order to cross the intersection and reduce the total delay of vehicle 2. In the other hand, vehicle 1 could not cooperate by keeping the same speed and that will cause the reduction of its own delay time but will increase the delay of vehicle 2 (in case of rejecting the offered gap).

The proposed game is considered “a mixed-motive game” as the drivers behavior could be somewhere between cooperative and non-cooperative. The structure of the gap acc/rej game is divided into: players, actions, information set, strategies, pay-offs, outcomes and equilibrium as illustrated in Figure 4.

The **players** are: the second opposing vehicle or the vehicle of the main approach (Player 1), and the vehicle waiting for appropriate gap to cross or the vehicle of the minor approach (Player 2). Each player has a choices of actions, Player 1 could decelerate at the intersection i.e. cooperate with player 2 or keep the same speed, i.e. not cooperate. For Player 2, s/he has the choice either to accept the offered gap, i.e. cooperate, or reject the offered gap, i.e. not cooperate.

Each player needs an **information** set in order to take an action in the game. It is proposed to use the DSRC for communications between moving vehicles. Each player (vehicle) knows the exact time and location for the other player in a second by second basis. The information is complete as all strategies and pay-offs are known for all players in the same time. Also, the information is perfect as all players know the **actions** taken by each player. The gap acceptance/rejection is proposed to be done through an agent implemented inside the vehicle that gives the driver the appropriate decision.
Figure 4: Gap Acceptance/Rejection Game structure

The **pay-off** or the negative benefit (loss) for each player corresponding to each action is proposed in this game to be equal to the delay time value. The delay time is equal to the time difference between the time of the uninterrupted (non-stop) trajectory and the time after taking an action by the player. As presented in Figure 2, for Player 1, in the case of cooperating “deceleration”, the delay (loss in time) is equal to (t2 - t2’) and for not cooperating “the same speed”, the loss of time is simply equal to zero (t2’-t2’).
For player 2, the delay is equal to \((t_2 - t_3)\) in case of cooperation “gap acceptance” and is will be equal to \((t_4 - t_3)\) for not cooperation “gap rejection”. In some cases, although the offered gap could be smaller than the critical gap and player 1 is not cooperating (not reducing the speed); Player 2 could misjudge and choose to cooperate (accept the gap). The proposed pay-off combination is equal to the pay-off of (Cooperate-Cooperate) case multiplied by a constant factor \((K)\), to indicate a large delay for a crash possibility. The pay-off matrix for different strategies combination is presented in Table 1. In the matrix, all Pay-off values have negative signs to indicate the loss in any actions and the purpose is to minimize the loss value. The lower value indicates the pay-off for Player 1 and the upper value is for Player 2.

Table 1: Pay-off matrix for Gap Acceptance/Rejection Game

<table>
<thead>
<tr>
<th>Player 1 (Vehicle 1)</th>
<th>Player 2 (Vehicle 2)</th>
<th>Cooperate (Accept the offered gap)</th>
<th>Not Cooperate (Reject the offered gap)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperate (Decelerate, i.e. reduce speed)</td>
<td>Cooperate</td>
<td>(- (t_2 - t_3))</td>
<td>(- (t_4 - t_3))</td>
</tr>
<tr>
<td></td>
<td>Not Cooperate</td>
<td>(- (t_2 - t_2'))</td>
<td>(- (t_4 - t_3))</td>
</tr>
<tr>
<td>Not Cooperate (Remain the same speed)</td>
<td>Cooperate</td>
<td>(-K (t_2 - t_3))</td>
<td>(- (t_4 - t_3))</td>
</tr>
<tr>
<td></td>
<td>Not Cooperate</td>
<td>(-K (t_2 - t_2'))</td>
<td>(- (t_2' - t_2'))</td>
</tr>
</tbody>
</table>

As mentioned before, the Gap Acceptance/Rejection game begins with having an expected gap less than the acceptable (critical) gap and this gap is negotiable. Player 1 has the first move to choose between two actions: Cooperate (decelerate for offering a larger gap to the second player) or not cooperate (remain the same speed). Consequently, Player 2 could cooperate (accept the offered gap) or not cooperate (reject the offered gap). From Table 1, if Player 1 chooses to “Cooperate”, the best strategy (less delay) for Player 2 will be “Cooperate” and thus this strategy combination will represent a first “Nash Equilibrium I” point. In the case of Player 1 chooses “Not cooperate”, Player 2 will be obligated to choose “Not cooperate” and this strategy combination will be the second “Nash equilibrium II”. Each of the Nash equilibria in the “Gap Acc/Rej mixed motive game” is considered a “Pareto-efficient”. Pareto efficient (or Pareto optimal) [5] is the strategy combination that assure no other strategy combination could offer an increase of a player pay-off without decreasing the other player pay-off.

The minimax strategy is this game is unstable as each player is willing to deviate from it to achieve a greater pay-off. If Player rather to choose the first equilibrium point or in other words agree to cooperate, it will indicate that he is exhibiting unselfish behavior. Game with this type of action is called “Heroic game” because Player 1 deviates from the minimax strategy to benefit the other player more than himself. In the other hand, if Player 1 choose to “Not cooperate” at the second equilibrium point, this
game will called “Leadership game” as he prefers to get more benefit than the other player[4]. Figure 5 illustrates the different equilibrium points and the minimax strategy. For this kind of games, the first move for player 1 will control the game.

**Figure 5: The equilibrium strategy combination for the Gap Acceptance/Rejection game**

**INTERSECTION DECISION SUPPORT PROCESS:**

It is proposed a driving assistance system that is implemented inside the vehicle and contains a storage device. This storage device is responsible for collecting all the information related to the history of gap acceptance behavior for the driver. The database information contain the driver decision (accept or reject) and all the corresponding parameters like vehicle characteristics, surface, intersection properties, travel time needed and level of acceleration (K) used by the driver. In addition, the agent inside the car will be receiving weather information from a station agency, in order to relate the impact of weather and the gap acceptance behavior.

All these information are used to build the pattern of driver decision making for different gap acceptance scenarios by applying game theory approach. The following diagram in Figure 6, is illustrating the framework for the system implemented inside the vehicle for making the gap acceptance/rejection decision that are used as Intellidrive Decision Support. The diagram is showing the processing of data inside the proposed system in the vehicle facing gap acceptance/rejection decisions. After accomplishing the database of the system, it is ready to receive certain input like the characteristics of the intersection and the surface, and the gap size offered to the driver. From these inputs and the buildup database, the system could estimate the output as decision guidance for the driver whether to accept or reject the offered gap.
After storing the different driver, intersection and environment characteristics, the agent inside the vehicle will process all this information. Afterward, the agent will apply game theory algorithm with the opposing vehicles using DSRC for providing the driver the appropriate decision (accept or reject the offered gap).

Figure 6: The framework of the proposed system inside the vehicle
In summary, it is proposed an innovative framework for the coordination of physical characteristics of the vehicle and the Intellidrive agency (V2V communications) for decision making process. The system will give the driver the appropriate guidance for gap acceptance/rejection decision for intersection crashes prevention. It is anticipated that this research will contribute in the future of intelligent transportation system (ITS), IntelliDrive systems and severe weather protection.

REFERENCES