An Integrated Intelligent Intersection Control System (III-CS) for Safety Improvement

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Introduction

• High-speed intersections often plagued by
  • Angle crashes & rear-end crashes

• An *Integrated intelligent intersection control system (III-CS)* has been developed to minimize the likelihood of having such crashes with *safety-based* control strategies

• Key system components:
  • Long-range sensors
  • Controller
  • In-cabinet computer
  • Communication hardware

• Control strategies
  • Dynamic all-red extension (DARE)
  • Dynamic green extension (DGE)
Control Strategies

Dynamic all-red extension (DARE)

- Preventing angle crashes by detecting red-light running (RLR) vehicles
- Has been implemented since the previous phase (Park et al., 2018)

All red phase starts

\[ T = 0 \]
\[ AR = 2.0 \text{ (all red)} \]

Any vehicle's speed above the **thresholds** and AR is extendable?

\[ T < AR? \]

- NO
- YES

End All red

Can the vehicle clear the intersection without extension?

\[ \text{Update AR} \]
\[ AR = AR + \text{extension} \]

\[ T = T + 0.1 \]
Control Strategies (Cont’d)

• Dynamic green extension (DGE)
  • **Purpose**: Minimizing the probability of incurring *rear-end crashes*
    – DGE extends the green phase up to the duration of having the *minimal risk* of rear-end collisions.

  – Risks of rear-end collision: can be measured by “*the estimated number of vehicles trapped in the dilemma zone*”

  ![Diagram showing risk and time with G(fixed) and G(ext) phases, and optimal point at risk minimal.]

Threshold and Comparison-based Logic

The key feature of the III-CS: Comparison-based logic to making decisions by *comparing current and future risks*

**Threshold-based decisions (conventional)**
- Set a threshold to extend the green phase (e.g., 1 vehicle in DZ or 2 vehicles in DZ)
- Works well in low-volume conditions
- However, will always extend to green when with high volumes (Zegeer, & Deen, 1978) or with multiple approaching lanes

[Diagram showing risk levels and green phase extension]

Will always extend to maximum green, hence green phase termination is *irrelevant to the risk level* and may terminate at higher risks.
Comparison-based decisions (proposed)

- Make decisions by **comparing current and future risks**
- Even with heavy volumes, will select the optimal timing for phase transition, which has lowest risks

![Diagram showing decision-making process with risk comparison and time axis.](image-url)
The Proposed Algorithm – DGT

Major steps of DGT

**Step 1** Begin the green phase of high-speed approaches

**Step 2** Retrieve the real-time data from the sensors

**Step 3** Compare the current and future risks in real-time

**Step 4** Determine if the window of dynamic green has begun

**Step 5** Determine whether to change from green to yellow phase

**Step 6** End DGT module, begin DARE module
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- Long-range wide sensors can update the following information at the interval of every 0.13(s) and cover the range of 500 - 1000(ft):
  - time-varying speed [MPH] of each vehicle
  - time-varying position [ft] of each vehicle
  - Time-to-stop-line (TSSL) [s] of each vehicle
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How to Predict Vehicles in DZ 1(sec) later?

- **Critical issue**: how to predict vehicles in DZ 1(sec) later?
  - In order to execute comparison-based logic
- **Proposed Method**: By shifting the dilemma zone, 1 second in terms of time-to-stop-line,
  - Because the relative distribution between vehicles and the dilemma zone will be the same
The Proposed Algorithm – DGT

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The **fixed** portion of green phase cannot be altered

The **dynamic** portion of the green phase

If the within the time window of the dynamic green:
- Go to step 5
Else: go back to step 2

Time
The Proposed Algorithm – DGT

Major steps of DGT

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If current risk is lowest

- **Compare with past**- The green extension one second earlier has expired (current risk lower than 1 sec earlier)
- **Compare with projected future**- And no further extension has been called (current risk no higher than 1 sec later)
- **Then** change to yellow phase

Else If the maximum green has reached

- **Then** change to yellow phase

Else

Repeat step 2

**Maximum green:**
- $g_{Max}$ for isolated intersections
- “Yield Point” in coordinated intersections
The Proposed Algorithm – DGT

Major steps of DGT

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Sites

DEPLOYED WITH DZPS (WITHOUT DGE)

DEPLOYED WITH III-CS

Planned deployment of III-CS

Figure background: https://mnadv.org
Stop line - 475 ft
475 - 1,000 ft
Stop line - 435 ft
435 - 1,000 ft

LEGENDS
● Sensor
Coverage of sensor
## Results - DARE

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cycles</td>
<td>92</td>
<td>123</td>
<td>196</td>
</tr>
<tr>
<td>No. of RLRs</td>
<td>11</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>RLR/cycle</td>
<td>0.119</td>
<td>0.065</td>
<td>0.116</td>
</tr>
<tr>
<td>No. of RLRs not cleared after 2-sec default AR</td>
<td>2</td>
<td>3</td>
<td>7</td>
</tr>
</tbody>
</table>

### DARE Activations

<table>
<thead>
<tr>
<th></th>
<th>Before Apri-10-2019</th>
<th>After Jan-28-2021</th>
<th>After Mar-22-2021</th>
</tr>
</thead>
<tbody>
<tr>
<td># AR-Extension actions</td>
<td>N/A</td>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td># False alarm</td>
<td>N/A</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td># Missed call</td>
<td>N/A</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Missed call rate (%)</td>
<td>N/A</td>
<td>0% (0/3)</td>
<td>0% (0/7)</td>
</tr>
<tr>
<td>Detection rate (%)</td>
<td>N/A</td>
<td>100% (3/3)</td>
<td>100% (7/7)</td>
</tr>
<tr>
<td>False alarm rate (%)</td>
<td>N/A</td>
<td>7.3% (9/123)</td>
<td>11.7% (23/196)</td>
</tr>
</tbody>
</table>

RLR: Red-light runner
AR: All-red interval
Results-DGE

Samples from the DGE’s actions:

- **Optimal activation**: the decisions by the DGE indeed resulted in a lower collision risk over the subsequent intervals based on the traffic conditions and the number of vehicles in the dilemma zone.
- **Non-optimal activation**: the DGE’s decisions did not result in a reduction in the collision risk over the subsequent intervals
- **Incorrect call**: the DGE failed to extend the green time

<table>
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<tr>
<th></th>
<th>After Jan-28-2021</th>
<th>After Mar-22-2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of optimal DGE activation</td>
<td>66.7% (72/108)</td>
<td>81.3% (87/107)</td>
</tr>
<tr>
<td>(Number of optimal activations/ Number of activations)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate of non-optimal activation</td>
<td>30.6% (33/108)</td>
<td>18.7% (20/107)</td>
</tr>
<tr>
<td>(Number of non-optimal activations/ Number of activations)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incorrect call rate</td>
<td>2.7% (3/108)</td>
<td>0.0% (0/107)</td>
</tr>
<tr>
<td>(Number of incorrect activations/Number of activations)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Summary

• Using the hardware for the previously-developed **dynamic all-red extension (DARE)** for dilemma zone protection system (DZPS), III-CS further is further embodied with a **dynamic green extension (DGE)** to prevent rear-end collisions.

• III-CS has identified potential risks.
  • Risk of angle crashes reduced by DARE
  • Risk of rear-end crashes reduced by DGE

• III-CS has proved to effectively reduce the risk of collisions during the field deployment, which can be observed from
  • High **red-light runner detection rate** of DARE (100%)
  • High **optimal activation** of DGE (66.7%, 81.3%)
Extensions

• Integrate pedestrian protection function to the current system
  – Delay the pedestrian phase or alert pedestrians when there is a red-light runner

• Implement the system to an arterial to further improve its effectiveness
References


THANK YOU!

For additional Questions, please contact
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