# Task Analysis of Intersection Driving Scenarios: Information Processing Bottlenecks

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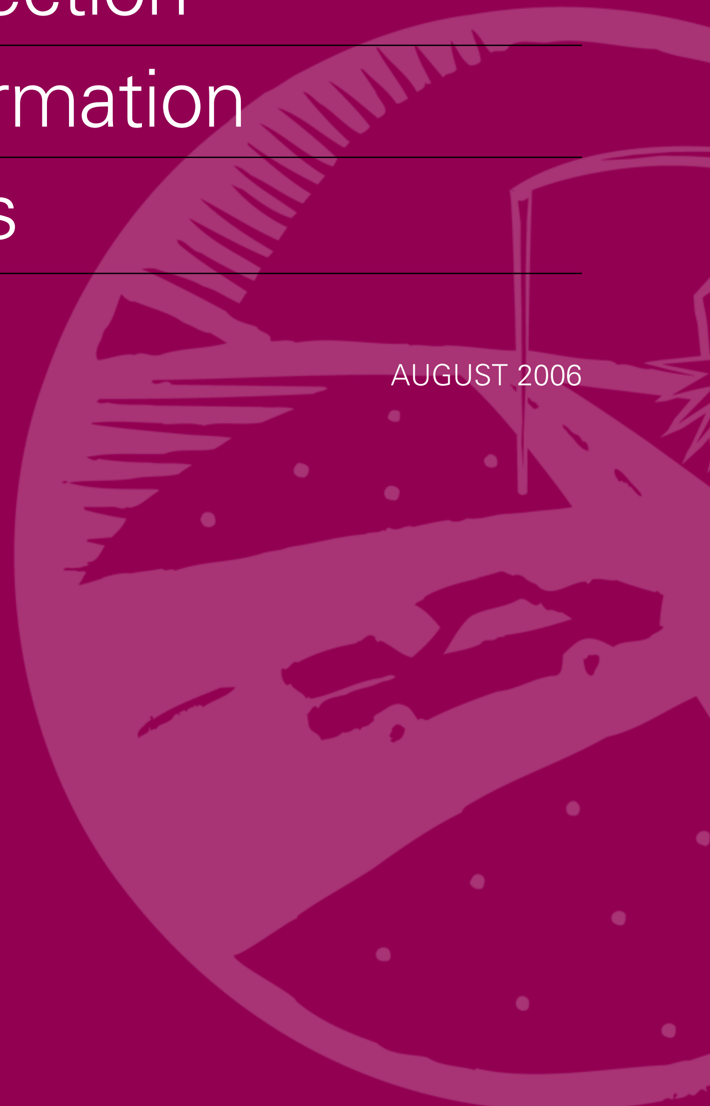

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# FOREWORD

The purpose of this report is to identify the information processing bottlenecks that drivers face in specific intersection driving scenarios. These bottlenecks represent situations in which drivers may become overloaded by driving demands, which could result in drivers conducting important driving tasks improperly or skipping certain tasks altogether. To identify and characterize information processing bottlenecks, this report presents a series of task analyses to determine key functions performed by drivers as they approach and navigate through different intersection scenarios. These task analyses focus on identifying the underlying information processing elements, including the perceptual, cognitive, and psychomotor subtasks associated with each individual driving task. A key benefit of using a task analysis approach is that it provides specific information about driver activities at various points during intersection navigation. This level of information is not made available using other approaches, such as crash data analyses, performance studies, and focus group research. This information about driver activities also can be quantified in relation to overall workload to identify when and under what conditions information processing bottlenecks occur.

Michael Trentacoste
Director, Office of Safety Research
and Development

## Notice



## Quality Assurance Statement

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16. Abstract


The purpose of this report is to identify the information processing bottlenecks that drivers face in specific intersection driving scenarios. These bottlenecks represent situations in which drivers may become overloaded by driving demands, which could result in drivers conducting important driving tasks in improper fashion or skipping certain tasks altogether.

To identify and characterize information processing bottlenecks, this report presents a series of task analyses to determine key functions performed by drivers as they approach and navigate through different intersection scenarios. The focus of this task analysis is on identifying the underlying information processing elements, including the perceptual, cognitive, and psychomotor subtasks associated with each individual driving task. Seven distinct driving scenarios were investigated in the task analysis, and each scenario was successively separated into segments, tasks, and subtasks/information processing elements. The scenarios included in the analysis were: (1) left turn on green light, (2) left turn on yellow light, (3) straight on yellow light, (4) straight on green light, (5) right turn on green light, (6) right turn on red light, and (7) stop on red light.

Appendix A discusses in detail the equations and assumptions associated with the development of the vehicle timing/dynamics calculations performed for each of the seven driving scenarios included in the effort.


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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| $^oF$ | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | $^oC$ |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| $^oC$ | Celsius | 1.8C+32 | Fahrenheit | $^oF$ |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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## LIST OF ACRONYMS

AASHTO ................................. American Association of State Highway and Transportation Officials
FHWA........................................................................................ Federal Highway Administration
GES.............................................................................................................. General Estimates System
LTAP/LD ......................................................................... left turn across path—lateral direction conflict
LTAP/OD..................................................................left turn across path—opposite direction conflict
LVM ........................................................................................................... lead-vehicle moving
LVS ...........................................................................................................lead-vehicle stationary
MSK..........................................................................................................meter-second-kilogram
MUTCD .................................................................................Manual of Uniform Traffic Control Devices
NA.....................................................................................................................................not applicable
POV........................................................................................................... principle other vehicle
RT ................................................................................................................................. reaction time
SI....................................................................................................International System of Units
TTC ...................................................................................................................... time-to-collision

# SECTION 1. INTRODUCTION

Intersection navigation is a particularly hazardous component of driving. For example, in 2003, more than 9,213 Americans lost their lives as a result of intersection-related crashes.(1) In total, intersection-related crashes account for more than 2.7 million crashes each year, which amounts to more than 45 percent of all reported crashes.(1) Even though intersections comprise just a small amount of the total roadway surface area, they contribute to a relatively high proportion of crashes because they are the critical points in the roadway system where traffic movements are most frequently in conflict with each other.

In addition to a greater frequency of conflicts, intersections generally are more complex and difficult to navigate than most other stretches of roadway. More specifically, intersections can be visually complex, requiring that drivers scan several different areas and keep track of several different elements to get the information they need to safely pass. Also, there are more hazards to deal with in terms of pedestrians and other traffic, such as turning and crossing vehicles that can encroach into a driver's path. Intersections also represent action points in which drivers may frequently have to make a response based on emerging traffic conditions under time pressure (e.g., change lanes to continue past stopping vehicles or decide to stop on a yellow light). Thus, intersection driving involves a multitude of different elements and hazards that can combine to increase the difficulty and workload that drivers face. When drivers are unable to meet these higher demands, their risk of making critical driving errors that can lead to conflicts with other road users also increases.(2)

The purpose of this report is to identify the information processing bottlenecks that drivers face in specific intersection driving scenarios. These bottlenecks represent situations in which drivers may become overloaded by driving demands, which could result in drivers conducting important driving tasks in improper fashion (e.g., taking too quick a look at oncoming traffic while turning left and failing to see an oncoming vehicle) or skipping certain tasks altogether (e.g., failing to check the blind spot while making a lane change under time pressure). Information processing bottlenecks can arise as the complexity/difficulty of normal driving tasks is increased or as additional tasks are added, or both, as drivers deal with emerging situations that require analysis and appropriate responses. Identifying and characterizing these bottlenecks can provide useful information for future safety efforts by identifying situations in which drivers could benefit from countermeasures that reduce driving demands, and also by identifying the types of measures that would be most relevant to the underlying problems.

To identify and characterize information processing bottlenecks, this report presents a series of task analyses to determine key functions performed by drivers as they approach and navigate through different intersection scenarios. A task analysis is the systematic analysis or breakdown of how specific tasks are accomplished in a situation, such as what subtasks are required and in what sequence they occur. The focus of the present task analysis is on identifying the underlying information processing elements, including the perceptual, cognitive, and psychomotor subtasks associated with each individual driving task. A key benefit of using a task analysis approach is that it provides specific information about driver activities at various points during intersection navigation that is not available in other approaches, such as crash data analyses, performance studies, and focus group research. This information about driver activities can also be quantified in terms of overall workload to identify when and under what conditions that information processing bottlenecks occur.

Seven distinct driving scenarios were investigated in the task analysis. Each scenario was then separated into segments, tasks, and subtasks/information processing elements. Where possible, existing task analyses were used as a starting point for the task analyses provided in this report.

The body of this report contains three technical sections. Section 2 describes the methods used to conduct the task analyses. It includes a description of the basis for the task analyses, the process of selecting scenarios to include in the task analyses, and procedures used to develop and present the task analyses. Section 3 provides the results from the individual task analyses. The results are presented in seven subsections, corresponding to the seven unique intersection driving scenarios captured in the task analyses. Each scenario includes the following components:

- Basic description.
- Details and assumptions.
- Diagram of individual segments and vehicle locations within the scenario.
- Timeline of key activities, milestones, and constraints within the scenario.
- List of segments, tasks, and subtasks.
- Detailed analysis of individual segments, including information processing elements, workload estimates, a scenario diagram, and an analysis of task timing and duration characteristics.
- Profiles of total and average workload estimates.
- Summaries of key bottlenecks, constraints, and driving challenges.

Section 4 provides a summary of key findings and conclusions from the task analyses. Appendix A provides a detailed discussion of the equations and assumptions associated with the development of the vehicle timing and dynamics calculations performed for each of the seven driving scenarios included in the report.

# SECTION 2. METHODS

This section describes the methods used to conduct a task analysis for each of seven urban signalized intersection scenarios. The section includes the methodology for selecting the scenarios and conducting the various analyses in this report including the task analysis tables, segment timelines, segment analyses, and scenario-wide analyses.

## SCENARIO SELECTION

The first step in this effort was to develop a list of candidate scenarios. This initial list covered different combinations of intersection control-type (e.g., stop sign-controlled, signalized), configuration (e.g., three-leg, multilane), location (e.g., urban, rural), and maneuver (e.g., left-turn, straight through). These scenarios were prioritized based primarily on crash data, but also for potential involvement of pedestrians and cyclists, and if countermeasures existed to address related safety issues. It became apparent from this preliminary analysis that urban signalized intersection scenarios tended to have a higher priority than other scenarios. Based on this information and in consultation with the Federal Highway Administration (FHWA), a decision was made to limit the task analysis to urban signalized intersections.

Scenarios were developed for the following maneuvers at urban signalized intersections:

- Scenario 1—Left turn on green light.
- Scenario 2—Left turn on yellow light.
- Scenario 3—Straight on yellow light.
- Scenario 4—Straight on green light.
- Scenario 5—Right turn on green light.
- Scenario 6—Right turn on red light.
- Scenario 7—Stop on red light.

In addition to the basic maneuvers and conditions, some complicating factors (e.g., dilemma zone at yellow light change, lane changes) were included in some scenarios to increase the overall scenario difficulty and introduce a greater variety of driving elements.

All scenarios were based on the same four-lane (two lanes in each direction), four-leg intersection. Two-lane or three-leg configurations were not used because they did not provide significant information beyond what was already available in the baseline configuration. Also, focusing on a common configuration allowed the procedures to be simplified.

## SCENARIO ANALYSIS COMPONENTS

Each scenario analysis has several parts:

- Scenario description and assumptions.
- Scenario timeline.
- Task analysis table.
- Segment analyses.
- Scenario-wide analyses.

An outline diagram showing the organization of these components is shown in figure 1. Also, these components are described later in more detail.

**Scenario 1**
- Scenario description and assumptions
- Scenario diagram
- Scenario timeline
- Task analysis table
- Segment analysis
  - Segment 1
    - Segment task analysis table
      - Task 1
        - Perceptual subtask 1 and workload estimate
        - Cognitive subtask 1 and workload estimate
        - Psychomotor subtask 1 and workload estimate
        - …
        - Perceptual subtask *n* and workload estimate
        - Cognitive subtask *n* and workload estimate
        - Psychomotor subtask *n* and workload estimate
      - …
      - Task *n*
    - Segment diagram
    - Approximate task duration and sequence within segment timeframe
    - Potential contributions to high workload and information processing bottlenecks and mitigating factors
    - Task pacing and timing
  - …
  - Segment *n*
- Scenario-wide analysis

…

Scenario *n*

**Figure 1. An outline diagram showing organization of components of each scenario analysis.**

### Scenario Description and Assumptions

For each scenario, an overall description was provided that defined the basic layout and key assumption of the scenario (figure 2). The assumptions typically specified the intersection layout, traffic volume, and other conditions (e.g., actions of other drivers) that were relevant for determining the specific tasks involved and the scenario timelines. Included in the scenario description is a diagram that depicts the layout, basic infrastructure design, and key features of the scenario. This diagram also demarks the general regions associated with each scenario segment. In the scenario diagram and also in the segment diagrams, the subject vehicle is always shown in blue, while other vehicles are always shown in white. The scenario diagram also shows the hypothetical path of the target vehicle (green arrow) and approximate speed in kilometers per hour (km/h) during each segment.

**Scenario Timeline**

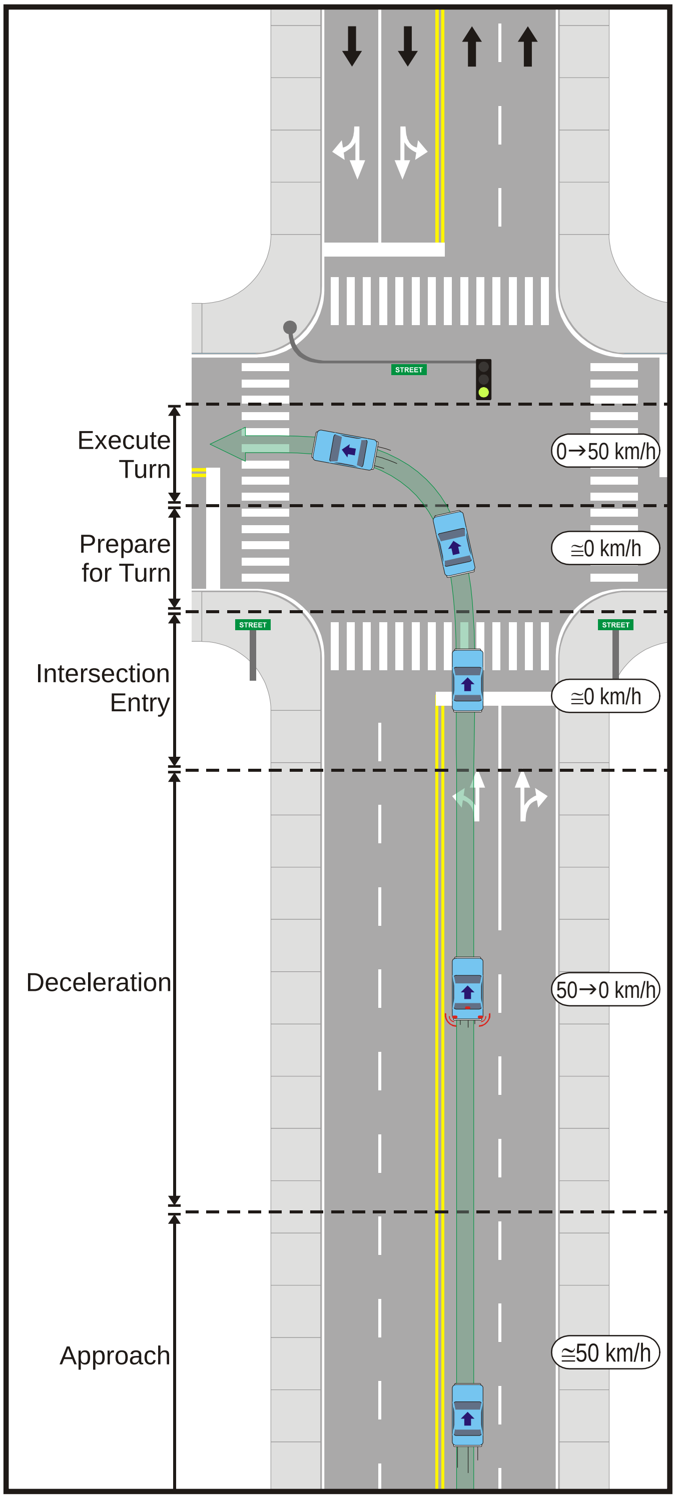
For each scenario, an approximate timeline showing the key temporal milestones was calculated based on vehicle kinematics. The milestones represented key events that can be pinpointed in time based on scenario dynamics and assumptions. These milestones were used to make judgments about the pacing of tasks within scenario segments (e.g., forced-paced versus self-paced), in addition to providing a basis for the overall sequencing of certain tasks. Appendix A provides the results of this analysis, including the equations and assumptions used to calculate each milestone.

The kinematic features of each scenario, which determined the temporal and physical placement of the milestones, included acceleration and deceleration rates, reaction times (RT), sight distances to the intersection, vehicle gap distances, and stopping distances. The scenario dynamics and any associated assumptions were based on established values and guidelines described in the human factors literature and roadway design manuals, such as the American Association of State Highway and Transportation Officials (AASHTO) *Green Book*(3) or the *Manual on Uniform Traffic Control Devices* (MUTCD).(4) Also, distances traveled and times of travel were calculated using standard motion equations found in any general physics text (e.g., reference(5) page 20, shows these equations). One notable point is that many scenarios included segments that had an interval with a variable time component, which represented intervals that either were long enough to effectively provide unlimited time to perform tasks or of a duration that was determined external to vehicle kinematic factors (e.g., waiting for lead vehicle to turn).

**Task Analysis Table**

Consistent with established procedures for conducting task analyses (6,7) and with past task analyses conducted by the contractor's staff,(8) the task analysis was developed using a top-down approach that successively separated driver intersection activities into scenarios, scenario segments, tasks, and subtasks. These components are presented in a single task analysis table organized by segments, tasks, and subtasks. Figure 2 shows an example scenario diagram with key assumptions.

**Example Scenario Diagram**




- Segments are demarked by dotted lines.
- Approximate speed in km/h is indicated on the right.

**Note: Illustration dimensions and vehicle positions are not to scale.**

**Scenario Details**

**Activity**:
Left Turn on Green Light

**Scenario Segments:**

- Approach
- Deceleration
- Intersection entry
- Prepare for turn
- Execute turn

**Intersection Configuration**:
Four-lane urban signalized intersection *without* a dedicated left-turn lane or a left-turn signal.

**Traffic Volume:**
Moderate (driving speeds are at speed limit and other lead/following/adjacent vehicles are present).

**Assumptions/Complicating Factors**:

- There is no dedicated left-turn lane or turn signal.
- The subject vehicle is following a turning vehicle and followed by another vehicle.
- The turn intersection is unfamiliar to the subject driver.
- No lane change is required to get into the turning lane.
- The turn must be made across oncoming traffic.
- Visibility of oncoming traffic is not blocked by intervening vehicles.

**Figure 2. Example scenario plan diagram identifying key assumptions.**

Scenarios were specified in detail with the assumptions about the intersection configuration, traffic conditions, and other complicating factors (e.g., level of traffic flow, additional maneuvers or tasks) defined in advance. The task analysis strictly addressed the defined scenario and did not provide a grand overview of all possible situations or outcomes; however, several of the scenarios contain components (e.g., lane change) or specific tasks that are general enough to be extracted and applied directly or with modification to other related intersection situations.

Each scenario was initially divided into a series of three to six consecutive segments, with each segment generally representing a related set of driving actions. The criteria for defining a segment was not fixed; however, a segment typically involved a group of actions geared toward a common goal or driving objective (e.g., decelerating, executing a turn). Differences in speed characteristics were also used to define segments. The reason for using speed was that different speeds are associated with different rates at which information passes by as well as different time constraints. Note that the demarcation into segments was done primarily for convenience of analysis and presentation; segmentation was not performed to imply that the overall driving task could be neatly carved up into discrete stages. In particular, several tasks (e.g., monitoring for hazards) cut across multiple segments. In these cases, crosscutting relationships were represented by separately including these tasks in each of the segments in which they were involved.

Within each segment, individual tasks that drivers should or must perform to safely navigate the intersection were identified. The tasks represented information that needed to be obtained, decisions that needed to be made, or actions that needed to be taken over the course of the segment. Note that in listing these tasks, the assumption was not that all tasks would be exhaustively performed during a segment; instead, the list was taken as an indicator of what drivers should do, with the understanding that some or many drivers most likely would perform only a subset of the tasks depending on the time available.

The tasks were described at an intermediate level of detail. More specifically, most of the tasks could have been further decomposed into a greater number of finer-grained tasks, but instead they were deliberately left at a more general level. This level of detail was chosen because it was compatible with the tools available for assigning workload estimates to the tasks (discussed later) and because it was general enough so that the relative sequence of tasks was mostly clear. In contrast, with a fine-grained level of detail, determining the sequence of the many resulting tasks would have been impractical and arbitrary.

Segment tasks were further divided based on the information processing elements (perceptual, cognitive, and psychomotor requirements) necessary to adequately perform each task. Each task had a subtask defined for each of the information processing domains, and these were used to derive the task workload estimates in the segment analyses (discussed later).

The primary source of information for segment tasks was the comprehensive driving task analysis conducted by McKnight and Adams;[9] however, in several cases, other sources such as Tijerina, Chovan, Pierowicz, and Hendricks,[10] which are derived from McKnight and Adams,[9] were used to organize the tasks into segments because they provided a more situation-specific distillation of the relevant task elements. Also, where applicable, additional task analyses and other research were used to supplement the information from McKnight and Adams.[9]

For the most part, the McKnight and Adams [9] task analysis and other research provided information about which tasks were involved in a segment/scenario, but they did not give complete information about the specific information-processing subtasks. To determine this information, the researchers identified details about the information-processing subtasks and any other necessary information based on expert judgment and other more general sources of driving behavior and human factors research.[11,12,13]

**Table 1. Information sources used in the task analysis.**

| **REFERENCES** |
|---|
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## SEGMENT ANALYSES

Each segment was separately analyzed in several different ways to provide information about potential information processing bottlenecks. The resulting information sources are described in the following text and shown in figure 3 (the numbers in the list correspond to figure 3 numbers):

1. Task workload estimate tables.
2. Segment diagram with distribution of potential information sources.
3. Relative timing and duration of segment tasks.
4. Summary of potential contributions to high workload and information processing bottlenecks and mitigating factors.

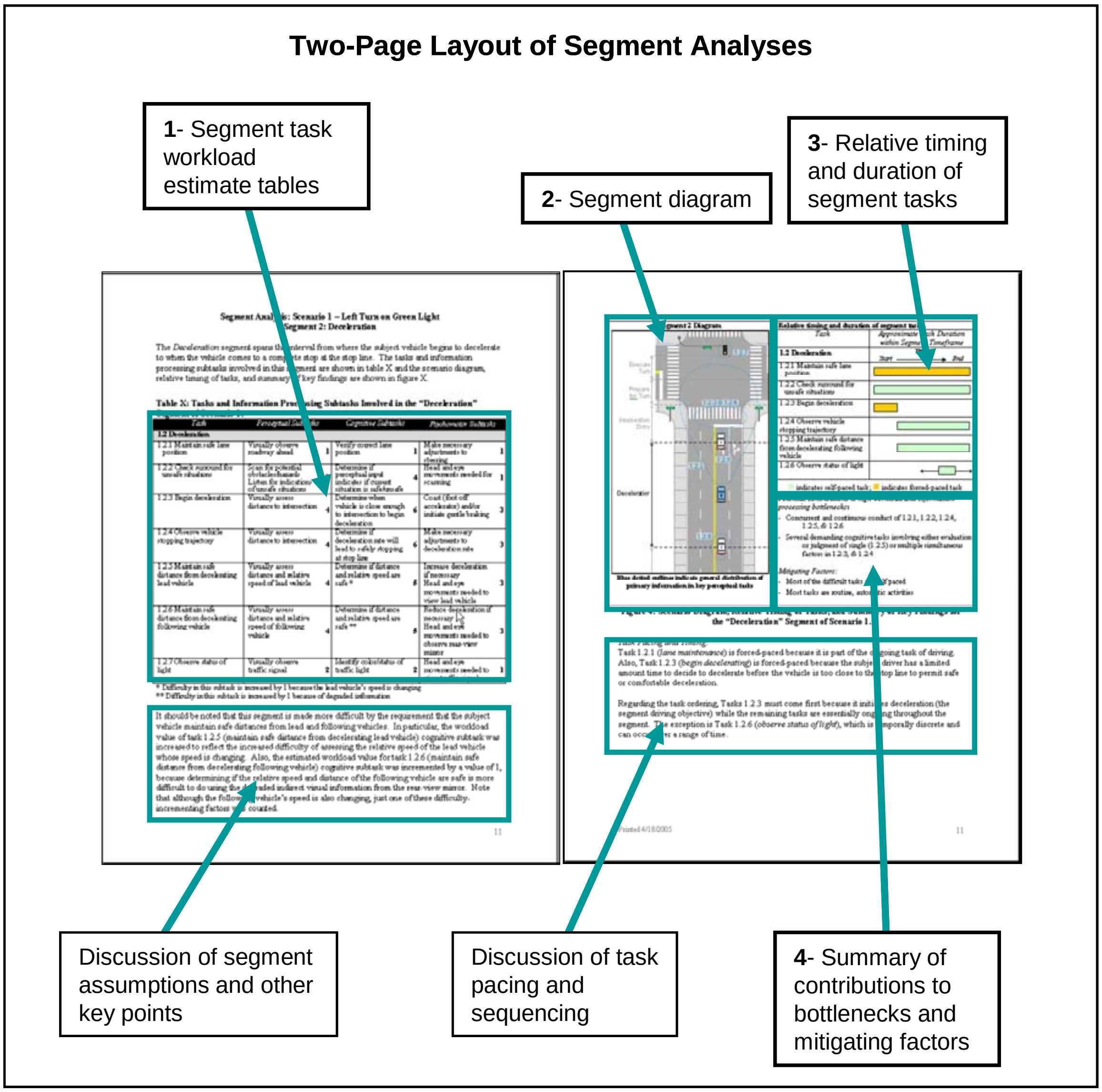



**Figure 3. Two-page layout of segment analysis showing key components.**

*1. Task workload estimate tables*—Duplicate the relevant sections of the task analysis tables with the addition of workload estimates for each of the information processing subtasks. These tables provided source information for evaluating the amount of workload that each task might hypothetically impose on a driver in the scenario. Workload was estimated using a workload estimation chart used by Campbell and Spiker[8] for helicopter pilots, and it was modified to reflect the driving environment as shown in table 2. These estimates were based on an ordinal scale that represents increasing workload. For each subtask, the primary subtask component was matched with a comparable task in the workload estimation chart, and the corresponding value was assigned. The mapping between subtask and chart estimation was not always straightforward, and sometimes it required researcher judgment to determine a value. Also, in some cases, complicating factors were present (e.g., degraded visual information) that made the task noticeably more difficult than the chart estimation. In these instances, the workload estimation was incremented by a value of 1 to reflect the increased difficulty, and the change was noted in the table footnotes.

To provide some level of validation for the process of assigning workload estimates, a review process was developed for calibrating the workload estimates and the corresponding tasks. More specifically, a panel of three senior researchers reviewed the workload estimates, in a process which involved separately assigning workload estimates to tasks from a pilot scenario. The reviewers then compared their results and came to a consensus on the appropriate workload estimates for each task/subtask. The resulting workload and task combinations served as reference examples for assigning workload estimates to related tasks in other scenarios. Any new or difficult-to-characterize tasks in subsequent scenarios were evaluated using the same review process.

One issue that complicated the assignment of workload values was that many driving tasks are routine and have been automatized so that they draw on fewer mental or attentional resources than when drivers first learned to perform these tasks.[14,15,16] To reflect this, the workload estimates would have to be lowered to reflect demands attenuated by automation. Also problematic is the possibility that in some situations, routine tasks may not be performed in a routine manner (e.g., identifying an intersection in an unfamiliar location). Thus, to simplify the allocation of workload estimates and avoid underestimating workload in potentially critical situations, the effects of automat city were considered on a case-by-case basis in the summary of potential complicating or mitigating factors and the scenario-wide analysis.

**Table 2. Workload estimation chart used to determine workload estimates for each segment task.**

| Estimate | Definition | Examples |
|---|---|---|
| **Perceptual** | | |
| **Estimate** | **Definition** | **Examples** |
| **1** | Register or detect visual or auditory stimulus; detect motion. | Detect brake lights or onset of headlights, and register vehicle heading and relative speed. Hear siren. |
| **2** | Discriminate differences in visual or auditory stimuli. | Determine traffic signal status. Determine if a sound is car horn or siren. |
| **3** | Visually inspect or general viewing/check or listen to sound. | Check fuel gauge status. Listen to music. View roadway feature. |
| **4** | Visually locate/align or orient to sound. | Determine position of a roadway object or feature. Determine the location from where a siren is coming. |
| **5** | Visually track/follow or monitor. | Track a potential hazard (e.g., cyclist approaching on cross-street). Monitor the position of a moving vehicle. |
| **6** | Visually read (symbol). | Read an unfamiliar street sign. |
| **7** | Visually scan/search or find object. | Search for hazards. Search for street signs. |
| **Cognitive** | | |
| **Estimate** | **Definition** | **Examples** |
| **1** | Simple, automatic response. | Perform emergency braking. Maintain lane. Respond automatically or with conditioned responses (shoulder check during lane change). |
| **2** | Alternative selection. | Decide response. Is traffic signal green? Is a vehicle stopped? |
| **3** | Sign/signal recognition. | Recognize street sign or familiar intersection or roadway furniture. Determine if-then relationships. |
| **4** | Evaluation/judgment of single aspect. | Judge distance to intersection. Determine whether a decelerating vehicle is stopping/time estimation. |
| **5** | Encoding/decoding, recall. | Remember instructions or an address. Interpret an unfamiliar traffic sign. Extrapolate posted traffic rules into allowable driving actions. |
| **6** | Evaluation/judgment of several aspects. | Judge the safe gap sizes given speed, distance, and traction of oncoming traffic. |
| **7** | Estimation, calculation, conversion. | Convert miles into kilometers. |
| **Psychomotor** | | |
| **Estimate** | **Definition** | **Examples** |
| **1** | Simple, feedback controlled, automatic responses. | Make steering wheel adjustments for lane maintenance. Head/eye movements. |
| **2** | Discrete actuation. | Depress button. Activate signal. Perform emergency braking. |
| **3** | Continuous adjustment. | Change extent to which the accelerator is depressed to change speed. Turn steering wheel through a turn. |
| **4** | Manipulative. | Tune digital radio. |
| **5** | Symbolic production. | Write down instructions. |
| **6** | Serial discrete manipulation. | Dial phone number. Use telematics system. |
| **7** | Temporally coordinated unlearned serial action. | Learn to drive manual transmission. |

*2. Segment diagram with distribution of potential information sources*—This diagram indicates the general distribution of important information sources for key tasks (dotted blue lines accompanied by blue task number labels). These were derived by broadly outlining likely location of task information with a significant perceptual element in typical intersections. In addition, to provide context for the positioning of the information sources, the diagram also shows the location of relevant roadway furniture and other pertinent information, in addition to the position and status of other nearby vehicles (e.g., if they are braking).

*3. Relative timing and duration of segment tasks*—This table shows the relative timing and duration of the segment tasks, as indicated by the relative position and width of the bars next to each task in the table. More specifically, scenario segments were divided into four to six intervals representing different time periods in which tasks could occur (the number of intervals was determined based on the need to represent successive tasks as not overlapping in time). The timing and duration estimates were based on the calculated scenario timelines and temporal milestones, logical precedence of the tasks, and whether individual tasks overlapped wholly or in part with other tasks. Thus, tasks with interval bars that precede those of other tasks are assumed to occur before those other tasks, whereas tasks that have bars occupying the same interval are assumed to occur concurrently. Note that just because tasks are shown as taking place concurrently, they are not necessarily performed simultaneously. Rather, these tasks are portrayed this way to denote the situation requires that those specific tasks are to be performed at that particular stage in the segment, regardless of whether the individual driver chooses to perform the tasks simultaneously, sequentially, or skip them altogether.

Another aspect of the driving tasks represented by this table is the task pacing. Individual tasks were defined as being either self-paced, meaning that the driver generally has significant control over the timing and execution of task performance, or forced-paced, whereby performance involves task timing and execution that is mostly determined by factors outside of the operator's control.(14) The different types of pacing are indicated by green and orange shading of the timeline bars, which represent self-paced and forced-paced tasks, respectively.

*4. Summary of potential contributions to high workload and information processing bottlenecks and mitigating factors*—This section summarizes some key factors identified in the other segment analysis components that either potentially contribute to information processing bottlenecks or act as mitigating factors. Typical contributing factors included concurrent tasks, several tasks with high workload estimates in a particular information processing domain, high time pressure, and forced-pacing of key tasks. Typical mitigating factors included self-pacing of key tasks or key tasks that were routine or likely to be automatic.

## SCENARIO-WIDE ANALYSIS

The purpose of the scenario-wide analysis was to integrate the different sources of information from all the segment analyses and identify potential information processing bottlenecks associated with each scenario.

The general strategy for finding bottlenecks was to identify situations in which drivers are required to perform multiple tasks concurrently. The assumption is that the more tasks that drivers must do at one time or in close temporal proximity, the more likely they are to make errors or voluntarily or involuntarily forgo performing some of those tasks. In addition to the temporal relationship between tasks, another aspect of performance that was considered important was the difficulty level (reflected in workload estimates) of the subtasks within a particular information processing domain. In this case, drivers would be more likely to make errors or skip tasks if the concurrent tasks are more difficult than if they are easy and perhaps automatic to perform.

The scenario-wide analysis involved three elements, described later:

1. Graphical workload demand profiles.
2. Table of key information processing issues.
3. Description of key bottlenecks.

*1. Graphical workload demand profiles*—Provide an overview of the workload demands across each scenario. Workload estimates from all segments were combined into a single scenario-wide workload profile that provides a general indication of where the areas of high workload demands are likely to be.

To capture the temporal overlap and overall difficulty of each information processing subtask, information about the temporal sequence of individual subtasks presented in the segment timeline tables was combined with the workload estimates from the segment task analysis tables. Essentially, the separate subtask workload estimates for all tasks that are active or in play during a segment interval were added together to provide a general indicator of the aggregate workload demand at a particular time.[1]

Two different workload profiles were generated for each scenario. The first indicated the total estimated workload rating for all tasks. It provided a measure of the overall workload during the scenario. The second profile indicated the average estimated workload per task for each scenario segment. It was essentially the total segment workload divided by the number of tasks that were active during a particular interval, and it generally represented how demanding the individual tasks in a segment were. For example, high levels of total workload can result from either having many tasks or from having fewer but more-demanding tasks; this profile indicated the extent to which each situation was true.

One point worth mentioning is that task pacing (self-paced or forced-paced) can have an effect on the difficulty of a particular subtask by affecting the time available to perform various tasks. Although task pacing information was not directly taken into account in the workload estimates, intervals in which key tasks were forced-paced were indicated on the demand profiles (shaded orange). This information was included to provide some additional context for identifying potential information processing bottlenecks.

[1] Although the underlying workload estimate scales are based on ordinal values, which lose meaningfulness when summed, our purpose was not to obtain totals that represented absolute workload values, but rather to simply identify intervals in which the workload demands were generally higher than other intervals. The underlying logic is that intervals with a greater number of tasks or with more difficult tasks, or both, should be more difficult (higher total) than intervals with fewer tasks or less difficult tasks.

An important consideration, when taking this approach, is the question of how different tasks potentially interfere with each other. As part of our analytical efforts, we considered a Multiple Resource Theory [17, 18, 19] perspective that focused on interference between tasks that shared the same resources, such as two concurrent visual search tasks.

The primary implication of this approach was that workload ratings across information processing subdomains were kept separate in the analysis. Note that there were significant constraints on how resource limitations could be applied to the current analysis. In particular, because driving is generally self-paced, it is difficult to identify clear instances where two tasks that draw on the same resources must necessarily overlap because drivers can delay conducting many tasks until there is time available to do so. Thus, for the most part, potential resource conflicts were addressed only on a general level by identifying them in the potential contributing factors section, discussed later.

The exception was in instances where resource-conflicting activities were forced-paced and drivers clearly had insufficient time to delay performing key tasks (e.g., during the decision to proceed when the light just turns yellow). In this case, tasks that must be sequential because they draw on the same resources (e.g., looking at two different locations in the driving scene) were shown as concurrent to represent the likely possibility of interference between tasks and the fact that drivers are likely to skip some of the tasks. This pattern shows up as higher combined workload profile levels, discussed later, than would have otherwise occurred if this approach had not been taken.

*2. Table of key information processing issues*—Groups key indicators of potential bottlenecks for each segment into a single table. The elements represented in this table include peaks in the workload demand profiles, information about task pacing, and key factors identified in the potential contributing and mitigating factors of the segment analyses.

*3. Description of key bottlenecks*—Describes the nature of key bottlenecks for each segment with a potential problem. In addition, it describes the key factors underlying the potential bottleneck.

## LIMITATIONS

It is important to acknowledge the inherent limitations of this work at the outset. This work was not designed to provide a definitive description of intersection driving; rather, it was an analytical activity with limited resources. It was just one part of a multipronged approach designed to assess the potential effectiveness of intersection countermeasures. As such, the most significant limitation is that this is an analytical and not an empirical research effort. In particular, no data were collected either to guide the identification of tasks and their temporal relationships, or to validate the results. Instead, the tasks were taken primarily from the comprehensive task analysis[9] and other supporting sources in table 2; however, this task analysis[9] was also an analytical exercise based on the opinions of a committee of driving experts whose primary goal was to provide information to develop driver training and testing programs.

This research is also limited because it relies on the judgment of the primary authors for several decisions about the inclusion of tasks, the sequence and allocation of tasks within segments, and the assignment of workload estimates. Although the authors have extensive experience in human factors, cognitive psychology, and driving research, various decisions about scenarios and included tasks may be biased by the driving experiences of the authors. To counter this potential problem, internal and external reviews (involving FHWA reviewers) were conducted to serve as a reality check on various aspects of the scenarios and related assumptions.

Another limitation of this research was that providing a sufficient level of detail in the tasks analysis required that the scenarios be specified to a relatively high degree with fixed assumptions about the scenarios. This requirement not only limited the generalizeability of some of the scenario elements, but it also required that many assumptions be made regarding a variety of aspects in each scenario. To the extent possible, attempts were made to justify assumptions based on logic, existing data, or constraints arising from the scenario kinematics. In some instances, none of these approaches could provide a clear basis for certain assumptions; as a result, assumptions became arbitrary. These instances are discussed in the task analysis as they occur.

Another limitation is that the general self-paced nature of most driving tasks and the corresponding control that drivers have over task sequencing makes it difficult to conduct detailed analyses of resource conflicts. Even though the task organization scheme used in this analysis (breaking scenarios down into segments) seems to lend itself to this type of microlevel analysis, the segment divisions are artificial, especially in situations where segments run together (e.g., *Approach* to *Decision to Proceed*, or *Approach* to *Prepare for Lane Change*) and do not necessarily reflect how drivers actually group tasks together. In addition, because driving is generally self-paced, tasks are likely to be displaced into other segments when time or resource constraints are encountered. Consequently, this temporal variability limits the degree to which it is possible to analyze direct resource conflicts between individual information processing subtasks (e.g., concurrent viewing of separate roadway elements), because in all but the most time-limited situations, drivers control if and when certain tasks are performed; thus, these conflicts were treated at a general level. Potential conflicts were identified, but with a few exceptions (e.g., very time-limited situations). No special cost or penalty was attributed to these situations.

A final important limitation is that the workload ratings are ordinal, which constrains what conclusions can be drawn from the workload profiles. This issue was discussed earlier; however, it is worth reiterating that the ordinal workload estimates lose meaningfulness when summed. Considering that the purpose was not to obtain totals that represented absolute workload values, but rather to identify intervals in which the workload demands were generally higher than other intervals, this limitation still allows some useful conclusions. The main point is that caution must be taken when basing results solely on the workload profiles, and a more appropriate approach, which we have tried to take, is to find instances in which multiple factors (e.g., forced pacing of tasks, short time budgets, and high workload) converge to indicate potential information processing bottlenecks.

# SECTION 3. RESULTS

This section describes the results of the task analysis. The results are divided into the seven scenarios analyzed, which are based on the following maneuvers at signalized intersections:

- Scenario 1—Left Turn on Green Light.
- Scenario 2—Left Turn on Yellow Light.
- Scenario 3—Straight on Yellow Light.
- Scenario 4—Straight on Green Light.
- Scenario 5—Right Turn on Green Light.
- Scenario 6—Right Turn on Red Light.
- Scenario 7—Stop on Red Light.

Each scenario can be divided into six segments, based on the action:

- Approach
- Prepare for Lane Change
- Deceleration/Stop
- Decision to proceed
- Intersection Entry
- Prepare for Turn

The following sections describe the scenarios.

## SCENARIO 1—LEFT TURN ON GREEN LIGHT

### Description

This scenario involves the subject vehicle making a left turn on a green light. Figure 4 shows the scenario diagram and provides additional details regarding the scenario. Briefly described, this scenario involves the subject driver identifying the intersection as the turn location, then decelerating to a stop. Following the stop, the subject vehicle advances into the intersection and waits for an appropriate gap in oncoming traffic before making the turn.

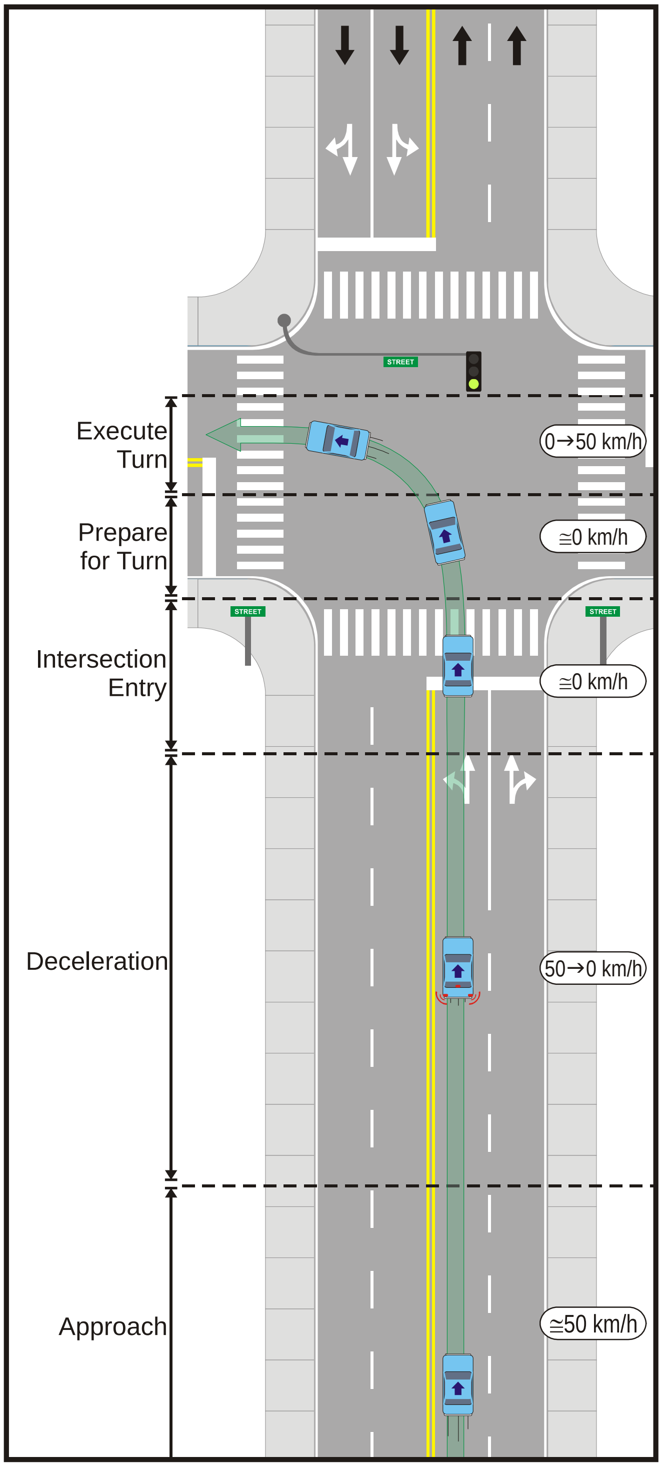
This scenario is divided into five segments (*Approach, Deceleration, Intersection Entry, Prepare for Turn,* and *Execute Turn*). The primary reasons this scenario was parsed into these particular segments were that each segment had a different overall driving goal and different speed characteristics (table 3).

**Table 3. Scenario 1—Left Turn on Green Light scenario partitioning based on driving objectives and speed characteristics by segment.**

| Segment | Driving Objectives | Speed Characteristics |
|---|---|---|
| *Approach* | Identify upcoming intersection as the location of the turn. | Traveling at full speed. |
| *Deceleration* | Stop at the intersection. | Controlled deceleration until stopped. |
| *Intersection entry* | Get into position to turn. | Slowly advance into position. |
| *Prepare for turn* | Wait for a safe gap in oncoming traffic. | Stopped until clear to go. |
| *Execute turn* | Make the turn. | Turning and accelerating up to speed. |

The crash data related to this scenario indicate several characteristics that are relevant to the task analysis for this scenario. In particular, the most common type of crash—occurring 76 percent of the time—in this scenario involves turning vehicles being struck by an oncoming vehicle.(20) This fact suggests that the activities preceding the turn (see *Prepare for Turn* segment in this scenario) are the most challenging for drivers. The most common causal crash factors include, in order of prevalence misjudging the gap, looking but not seeing oncoming traffic, view obstructed by intervening vehicles, and other vehicle violations.(20,21) If only incidents in which the subject vehicle stops before turning are considered (same as the current scenario), then the same factors are implicated; however, view obstructed by intervening vehicles becomes the most common cause for crashes. Figure 4 shows the scenario diagram and gives details and assumptions.

**Scenario 1 Diagram**




- Segments are demarked by dotted lines.
- Approximate speed in km/h is indicated on the right.

**Note: Illustration dimensions and vehicle positions are not to scale.**

**Scenario Details**

**Activity**:
Left Turn on a Green Light

**Scenario Segments:**
- Approach
- Deceleration
- Intersection entry
- Prepare for turn
- Execute turn

**Intersection Configuration**:
Four-lane urban signalized intersection *without* a dedicated left-turn lane or a left-turn signal.

**Traffic Volume:**
Moderate (driving speeds are at speed limit and other lead/following/adjacent vehicles are present).

**Assumptions/Complicating Factors**:
- There is no dedicated left-turn lane or turn signal.
- The subject vehicle is being followed by another vehicle.
- The turn intersection is unfamiliar to the subject driver.
- No lane change is required to get into the turning lane.
- The turn must be made across oncoming traffic.
- Visibility of oncoming traffic is not blocked by intervening vehicles.

**Figure 4. Scenario 1—Left Turn on Green Light diagram, details, and assumptions.**

Several assumptions were made about the aspects of the scenario situation. The justifications for these are summarized in figure 4 and more fully described in table 4.

**Table 4. Scenario 1—Left Turn on Green Light assumptions and corresponding justifications.**

| Assumption | Justification |
|---|---|
| There is no dedicated left turn lane or turn signal. | Excluding these items makes the task more difficult. A dedicated turn signal makes the task of judging a gap (one of the most common causal factors) trivial. |
| A left-turning vehicle is established in the intersection ahead, but no other vehicles are in front of the subject vehicle. | Including the turning vehicle adds some complexity to the Intersection Entry Segment, while excluding lead vehicles puts the onus on the subject vehicle to determine when to start decelerating (instead of just responding to the lead vehicle's deceleration). |
| The subject vehicle is being followed by another vehicle. | Including the following vehicle makes the deceleration-related tasks more demanding. |
| The turn intersection is unfamiliar to the subject driver. | Identifying an unfamiliar intersection as the turn interval is significantly more difficult than merely recognizing a familiar intersection. |
| No lane change is required to get into the turning lane. | Although lane changes are common, this element was left out to simplify segmentation, in order for it to be included in other scenarios. (See scenarios 4 and 6.) |
| The turn must be made across oncoming traffic. | This makes the decision about when to turn more difficult by requiring the subject driver to identify a safe gap in oncoming traffic. |
| Visibility of oncoming traffic is not blocked by intervening vehicles. | Although vision obstruction is the most commonly cited causal crash factor for this scenario, this element was not included because other research suggests that driver responses to this situation are complex and vary widely in ways that are impractical to model.(22) |

## Scenario Timeline

An approximate timeline showing the key temporal milestones for scenario 1 was calculated based on vehicle kinematics (figure 5). These milestones were used to make judgments about the pacing of tasks within segments, and they also provide a basis for the overall sequencing of certain tasks. Most segments included an interval with a variable time component, which represented intervals that either were long enough to effectively provide unlimited time to perform tasks or of a duration that was determined external to vehicle kinematic factors (e.g., waiting for lead vehicle to turn).

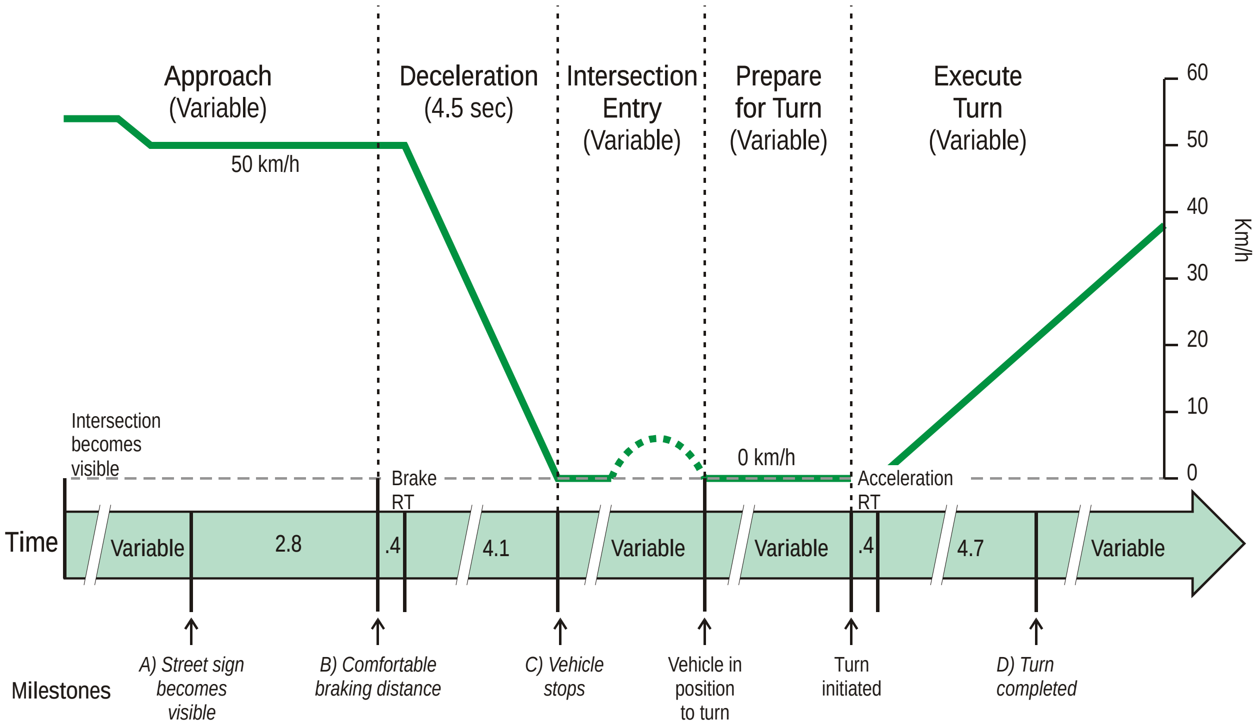



**Figure 5. Scenario 1—Left Turn on Green Light timeline depicting key segment phases duration and event/task milestones.**

## Task Analysis Table

The results of the task analysis organized by scenario segment are shown in table 5, the task analysis table. The results are duplicated for individual segments in the segment analyses tables in the next sections, which also more fully discuss the organization and content of the tasks and information processing subtasks.

**Table 5. Scenario 1—Left Turn on Green Light task analysis table.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **1.1. Approach** | | | |
| 1.1.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 1.1.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 1.1.3. Decelerate. | Visually assess distance to intersection. | Determine when vehicle is close enough to intersection to begin deceleration. | Coast (foot off accelerator) and/or gentle braking. |

**Table 5. Scenario 1—Left Turn on Green Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **1.1 Approach, *continued*** | | | |
| 1.1.4. Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location, and so forth. | Determine if any nonroutine actions are required. | Head and eye movements for scanning. |
| 1.1.5. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 1.1.6. Determine if the light is about to change. | Scan visual scene for key cues (e.g., pedestrian signal). | Determine if cues suggest that the light will soon change. | Head and eye movements for scanning. |
| 1.1.7. Identify intersection as correct turn intersection. | Scan visual scene for indicator landmarks or street signs. | Identify unfamiliar intersection as correct one, read street signs. | Head and eye movements for scanning. |
| 1.1.8. Activate turn signal. | Visually assess distance to intersection. | Determine if vehicle is close enough to start signaling. | Activate turn signal control. |
| **1.2. Deceleration** | | | |
| 1.2.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 1.2.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 1.2.3. Begin deceleration. | Visually assess distance to intersection. | Determine when vehicle is close enough to intersection to begin deceleration. | Coast (foot off accelerator) and/or initiate braking. |
| 1.2.4. Observe vehicle stopping trajectory. | Visually assess distance to intersection. | Determine whether deceleration rate will lead to safely stopping at stop line. | Make necessary adjustments to deceleration rate. |
| 1.2.5. Maintain safe distance from decelerating following vehicle. | Visually assess distance and relative speed of following vehicle. | Determine if following-vehicle closing trajectory is safe. | Reduce deceleration if necessary.<br>Head and eye movements to observe rearview mirror. |
| 1.2.6. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |

**Table 5. Scenario 1—Left Turn on Green Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **1.3. Intersection Entry** | | | |
| 1.3.1. Wait for lead vehicle to turn. | Visually observe position of lead vehicle. | Identify when lead vehicle exits the intersection. | Head and eye movements to view lead vehicle. |
| 1.3.2. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 1.3.3. Check for conflict with following vehicle. | Visually assess trajectory of following vehicle. | Determine if distance and speed of following vehicle indicate potential conflict. | Head and eye movements to observe rearview mirror. |
| 1.3.4. Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | Determine if crossing vehicles are stopped or will stop in time. | Head and eye movements for observing cross traffic. |
| 1.3.5. Advance into intersection. | Visually observe intersection. | Determine when vehicle is in position for turning. | Gently accelerate and brake. |
| **1.4. Prepare for Turn** | | | |
| 1.4.1. Look for gap in traffic. | Visually monitor oncoming traffic. | Determine distance and speed of oncoming traffic.<br>Determine if there is a gap sufficient for turning. | Head and eye movements to monitor oncoming traffic. |
| 1.4.2. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 1.4.3. Check for hazards in turn path. | Visually scan turn path to the left (especially crosswalk). | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | Head and eye movements to view left-turn path. |
| 1.4.4. Check for conflict with following vehicle. | Visually assess trajectory of following vehicle. | Determine if distance and speed of following vehicle indicate potential conflict. | Head and eye movements to observe rearview mirror. |

**Table 5. Scenario 1—Left Turn on Green Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **1.5. Execute Turn** | | | |
| 1.5.1. Accelerate to initiate turn. | Visually monitor oncoming traffic. | Determine that acceleration is sufficient to get vehicle through the gap in oncoming traffic. | Accelerate at necessary rate. Head and eye movements to view oncoming traffic. |
| 1.5.2. Steer into turn. | View turn path. | Determine that vehicle trajectory and lane position are appropriate. | Steer to the left and make necessary adjustments to stay in lane. |
| 1.5.3. Check for hazards in turn path. | Visually scan turn path to the left (especially crosswalk). | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | Head and eye movements to view left-turn path. |
| 1.5.4. Continue accelerating up to speed. | Visually observe roadway or lead vehicle. | Determine when traveling speed reached. | Accelerate at needed rate. Head and eye movements for viewing. |
| 1.5.5. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 1.5.6. Maintain safe distance from accelerating lead vehicle. | Visually assess distance and relative speed of lead vehicle. | Determine if lead-vehicle trajectory is safe. | Decrease acceleration if necessary.<br>Head and eye movements to view lead vehicle. |
| 1.5.7. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine if perceptual input indicates current situation is safe/unsafe. | Head and eye movements for scanning. |

## Segment Analysis

### *Scenario 1, Segment 1, Approach*

The *Approach* segment involves the subject vehicle traveling at full speed until the intersection is identified as the turn intersection and lasts until it is time to begin decelerating. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 6. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 6 and table 7.

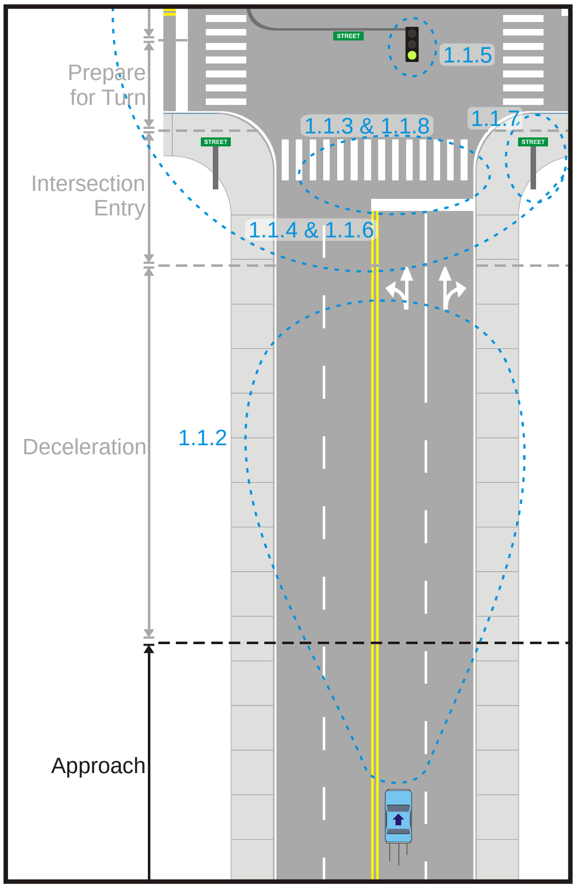
The workload estimates shown in table 6 and all subsequent segment task analysis tables are based on the workload estimation chart shown in table 2.

**Table 6. Scenario 1—Left Turn on Green Light *Approach* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 1.1.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 1.1.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 1.1.3 Decelerate. | Visually assess distance to intersection. | **4** | Determine when vehicle is close enough to intersection to begin deceleration. | **6** | Coast (foot off accelerator) and/or gentle braking. | **3** |
| 1.1.4 Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location. | **6** | Determine whether any nonroutine actions are required. | **6** | Head and eye movements for scanning. | **1** |
| 1.1.5 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 1.1.6 Determine if the light is about to change. | Scan visual scene for key cues (e.g., pedestrian signal). | **7** | Determine whether cues suggest that the light will soon change. | **6** | Head and eye movements for scanning. | **1** |
| 1.1.7 Identify intersection as correct turn intersection. | Scan visual scene for indicator landmarks or street signs. | **7** | Identify unfamiliar intersection as correct one—read street signs. | **5** | Head and eye movements for scanning. | **1** |
| 1.1.8 Activate turn signal. | Visually assess distance to intersection. | **4** | Determine if vehicle is close enough to start signaling. | **4** | Activate turn signal control. | **2** |

Several aspects about the task analysis and workload estimation warrant discussion. The first is that the deceleration that takes place in task 1.1.3 (*decelerate*) is not the same as the deceleration in the following segment which stops the vehicle. Instead, the task 1.1.3 deceleration is just general deceleration that should be part of any approach to an intersection.[9] Note also that task 1.1.7 (*identify intersection as turn intersection*) is a new task that is not indicated or suggested by any of the task analysis sources used,[9] but it is included because it is required by the scenario assumptions.

**Scenario 1, Segment 1 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 6. Scenario 1—Left Turn on Green Light *Approach* segment scenario diagram.**

**Table 7. Scenario 1—Left Turn on Green Light *Approach* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **1.1 Approach** | **Time** *Start* → *End* |
| 1.1.1 Maintain safe lane position. | F |
| 1.1.2 Check surround for unsafe situations. | S |
| 1.1.3 Decelerate. | S |
| 1.1.4 Identify intersection characteristics. | S |
| 1.1.5 Observe status of light. | ← S → |
| 1.1.6 Determine if the light is about to change. | S |
| 1.1.7 Identify intersection as correct turn intersection. | F |
| 1.1.8 Activate turn signal. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Frequent perceptual tasks involving scanning or reading in 1.1.2, 1.1.4, 1.1.6, and 1.1.7.
- Frequent cognitive tasks involving evaluation or judgment of several factors in 1.1.3, 1.1.4, and 1.1.6.
- Task 1.1.7 is a demanding forced-paced task that must be completed in a relatively short period of time.

***Mitigating factors:***

- Most of the difficult tasks are self-paced.
- Many tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 1.1.1 (lane maintenance) is forced-paced because it is part of the ongoing task of driving. Task 1.1.7 (identify intersection as turn location) is forced-paced because it is constrained by the fact that for an unfamiliar intersection, this task cannot be performed until the street signs are readable—yet it has to be done before it is too late to decelerate safely. Similarly, task 1.1.8 (activate signal) is also forced-paced because it must follow task 1.1.7, but precede deceleration (the next segment).

Regarding the task ordering, tasks 1.1.7 and 1.1.8 are confined to the latter parts of the segment because the subject driver has to be close enough to the intersection to read the street signs. In addition, because tasks 1.1.3 through 1.1.6 are self-paced, there are no barriers to performing them in advance of task 1.1.7 as long as the intersection is visible. Also, these are tasks that the subject driver must perform regardless of whether he or she is turning at this intersection or continuing straight; therefore, it makes sense that they would be done early. Finally, task 1.1.5 (*observe status of light*) can logically occur over a range of time.

### *Scenario 1, Segment 2, Deceleration*

The *Deceleration* segment spans the interval from where the subject vehicle begins to decelerate to when the vehicle comes to a complete stop at the stop line. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 8. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 7 and table 9.

**Table 8. Scenario 1—Left Turn on Green Light *Deceleration* segment tasks and information processing subtasks.**

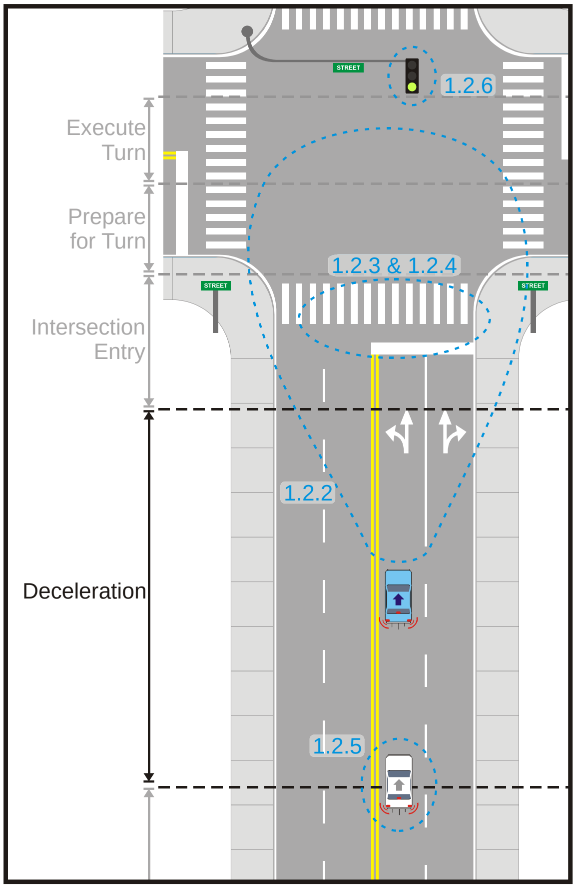
| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 1.2.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 1.2.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 1.2.3 Begin deceleration. | Visually assess distance to intersection. | **4** | Determine when vehicle is close enough to intersection to begin deceleration. | **6** | Coast (foot off accelerator) and/or initiate braking. | **3** |
| 1.2.4 Observe vehicle stopping trajectory. | Visually assess distance to intersection. | **4** | Determine if deceleration rate will lead to safely stopping at stop line. | **6** | Make necessary adjustments to deceleration rate. | **3** |
| 1.2.5 Maintain safe distance from decelerating following vehicle. | Visually assess distance and relative speed of following vehicle. | **4** | Determine if following-vehicle closing trajectory is safe.* | **5** | Reduce deceleration if necessary. Head and eye movements to observe rearview mirror. | **3** |
| 1.2.6 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |

* Difficulty in this subtask is increased by a value of 1 because of degraded information.

It is important to note that the task 1.2.5 (*maintain safe distance from decelerating following vehicle*) cognitive subtask was treated as involving the evaluation of a single dimension (workload estimate = 4), rather than as the evaluation of multiple dimensions (workload estimate = 6) based on relative speed and distance. This approach was taken because evidence suggests that drivers may evaluate time-to-arrival as a single integrated variable (*tau*) rather than as separate speed and distance components.[11] Also, the estimated workload value for the cognitive element of this task was incremented by a value of 1. This was done because determining the closing trajectory of the following vehicle is more difficult to accomplish using the degraded indirect visual information available from the rearview mirror. Note that this task is further complicated because the following vehicle's speed is also changing; however, the difficulty level was incremented only once to reflect these factors.

It is also noteworthy that although the subject driver may have determined in the previous segment that the light will not change to yellow soon, it is still necessary to check the traffic signal sometime during this segment. Doing so ensures that the driver did not misjudge the light duration or that the light status is not about to change.

**Scenario 1, Segment 2 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 7. Scenario 1—Left Turn on Green Light *Deceleration Segment* scenario diagram.**

**Table 9. Scenario 1—Left Turn on Green Light *Deceleration* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **1.2 Deceleration** | Time<br>*Start* → *End* |
| 1.2.1 Maintain safe lane position. | F (start to end) |
| 1.2.2 Check surround for unsafe situations. | S (start to end) |
| 1.2.3 Begin deceleration. | F (start) |
| 1.2.4 Observe vehicle stopping trajectory. | S (after 1.2.3 to end) |
| 1.2.5 Maintain safe distance from decelerating following vehicle. | S (after 1.2.3 to end) |
| 1.2.6 Observe status of light. | ← S → |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 1.2.1, 1.2.2, 1.2.4, 1.2.5, and 1.2.6.
- Several demanding cognitive tasks involving either evaluation or judgment of multiple simultaneous factors in 1.2.3, and 1.2.4 or a single factor under increased difficulty (1.2.5).

***Mitigating factors:***

- Most of the difficult tasks are self-paced.
- Most tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 1.2.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Also, task 1.2.3 (*begin decelerating*) is forced-paced because the subject driver has a limited amount of time to decide to decelerate before the vehicle is too close to the stop line to permit safe or comfortable deceleration.

Regarding the task ordering, task 1.2.3 must come first because it initiates deceleration (the segment driving objective), while the other tasks are essentially ongoing throughout the segment.

The exception is task 1.2.6 (*observe status of light*), which is temporally discrete and can occur over a range of time.

### *Scenario 1, Segment 3, Intersection Entry*

The *Intersection Entry* segment involves the subject vehicle entering the intersection from the stop line after the lead vehicle has turned. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 10, and the scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 8 and table 11.

**Table 10. Scenario 1—Left Turn on Green Light *Intersection Entry* segment tasks and information processing subtasks involved.**

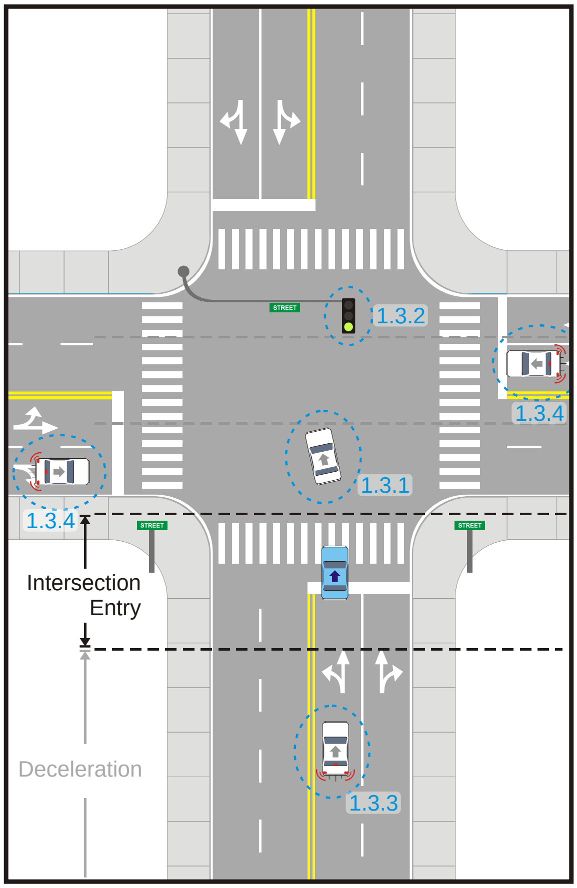
| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 1.3.1 Wait for lead vehicle to turn. | Visually observe position of lead vehicle. | **1** | Identify when lead vehicle exits the intersection. | **2** | Head and eye movements to view lead vehicle. | **1** |
| 1.3.2 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 1.3.3 Check for conflicts with following vehicle. | Visually assess trajectory of following vehicle. | **4** | Determine if following-vehicle closing trajectory is safe.* | **5** | Head and eye movements to observe rearview mirror. | **1** |
| 1.3.4 Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | **5** | Determine if crossing vehicles are stopped or will stop in time. | **4** | Head and eye movements for observing cross traffic. | **1** |
| 1.3.5 Advance into intersection. | Visually observe intersection. | **1** | Determine when vehicle is in an appropriate position for turning. | **4** | Gently accelerate and brake. | **3** |

* Difficulty in this subtask is increased by a value of 1 because of degraded information.

Several points about the task analysis warrant discussion. The first is that task 1.3.1 (*wait for lead vehicle to turn*) is not directly specified in the task analysis references used for this analysis.[9] This task is included because it is logically a necessary part of this segment. Also, although the subject driver probably has enough space to enter the intersection, the driver is assumed to wait at the stop line until the lead vehicle turns. This assumption was made for two reasons: to reduce the number of steps in this segment and have a default course of action if the intersection is not large enough for following drivers to establish themselves in the intersection. (Note that the workload is the same either way because the steps are sequential.)

Another assumption is that cross traffic is moving and in the process of slowing to a stop, which makes task 1.3.4 (*check for red-light-running cross traffic*) more difficult because it requires the subject driver to determine if the slowing vehicles are stopping rather than simply checking if the vehicles are stopped at the intersection. Finally, the estimated workload value for the task 1.3.3 (*check for conflicts with following vehicle*) cognitive element was incremented by a value of 1 because determining the closing trajectory of the following vehicle is more difficult to do using the degraded indirect visual information from the rearview mirror.

**Scenario 1, Segment 3 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 8. Scenario 1—Left Turn on Green Light *Intersection Entry* segment scenario diagram.**

**Table 11. Scenario 1—Left Turn on Green Light *Intersection Entry* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **1.3 Intersection Entry** | Time<br>*Start* → *End* |
| 1.3.1 Wait for lead vehicle to turn. | S |
| 1.3.2 Observe status of light. | S |
| 1.3.3 Check for conflicts with following vehicle. | S |
| 1.3.4 Check for red-light-running cross traffic. | S |
| 1.3.5 Advance into intersection. | S |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- There are no significant workload or information processing challenges in this segment.

***Mitigating factors:***

- All of the tasks are self-paced.
- Most tasks are routine, automatic activities.

*Task Pacing and Timing*—All tasks in this segment are self-paced. Although they are inherently limited by the duration of the green light phase, a prior assumption in this segment is that the light will remain green long enough for this to not be a significant constraint.

Regarding the task ordering, the subject driver must wait until the lead vehicle turns (task 1.3.1) before completing other tasks, except for tasks 1.3.2 and 1.3.3, which require periodic checking for the duration of the segment.

### *Scenario 1, Segment 4, Prepare for Turn*

The *Prepare for Turn* segment spans the time interval from when the subject vehicle stops after establishing itself in the intersection as the next turn vehicle to when the driver makes the decision that there is enough of a gap in oncoming traffic to safely make the turn. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 12. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 9 and table 13.

**Table 12. Scenario 1—Left Turn on Green Light *Prepare for Turn* segment tasks and information processing subtasks.**

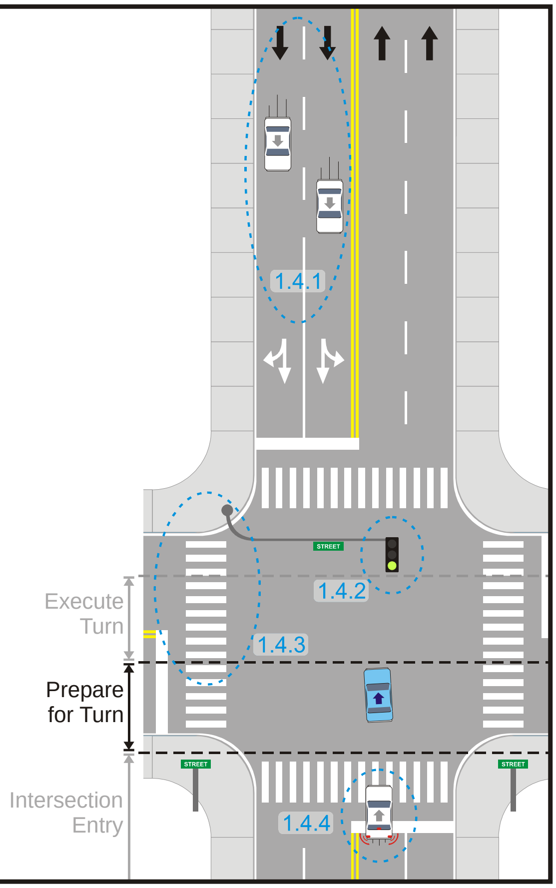
| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 1.4.1 Look for gap in traffic. | Visually monitor oncoming traffic. | **5** | Determine distance and speed of oncoming traffic. Determine if there is a gap sufficient for turning. | **6** | Head and eye movements to monitor oncoming traffic. | **1** |
| 1.4.2 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 1.4.3 Check for hazards in turn path. | Visually scan turn path to the left (especially crosswalk). | **7** | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | **4** | Head and eye movements to view left-turn path. | **1** |
| 1.4.4 Check for conflicts with following vehicle. | Visually assess trajectory of following vehicle. | **4** | Determine if following-vehicle closing trajectory is safe.* | **5** | Head and eye movements to observe rearview mirror. | **1** |

* Difficulty in this subtask is increased by a value of 1 because of degraded information.

Note that task 1.4.1 (*look for gap in traffic*) is likely to be the most common source of errors in this scenario because "misjudging the gap" and "looked but did not see oncoming traffic" are among the most commonly cited driver errors in this situation.[20, 21] Not only is the gap judgment task particularly difficult, but drivers also must continuously cycle their visual gaze among additional sources of key information (e.g., the traffic signal) throughout the environment while they are assessing the suitability of gaps in traffic. Note that with the subject vehicle stopped and the following vehicle likely traveling at slow speeds, task 1.4.4 may be unnecessary; however, it was included because the consequences of being rear-ended and possibly pushed into oncoming traffic are relatively severe. Also, the estimated workload value for the task 1.4.4 (*check for conflicts with following vehicle*) cognitive element was incremented by a value of 1, because determining the closing trajectory of the following vehicle is more difficult to do using degraded indirect visual information from the rearview mirror.

In this segment, no specific task is allocated for the decision to turn; rather, this decision is the result of the process of correctly identifying a suitable gap (task 1.4.1) and confirming that the turn path is free from hazards (task 1.4.3).

**Scenario 1, Segment 4 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 9. Scenario 1—Left Turn on Green Light *Prepare for Turn* segment scenario diagram.**

**Table 13. Scenario 1—Left Turn on Green Light *Prepare for Turn* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **1.4 Prepare for Turn** | **Time** *Start* → *End* |
| 1.4.1 Look for gap in traffic. | F |
| 1.4.2 Observe status of light. | F |
| 1.4.3 Check for hazards in turn path. | F |
| 1.4.4 Check for conflicts with following vehicle. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 1.4.1, 1.4.2, 1.4.3, and 1.4.4 under high time pressure.
- The majority of the time in this segment is likely to be taken by tasks that have either a relatively high cognitive workload (1.4.1, 1.4.4) or high perceptual workload (1.4.3).
- Task 1.4.1 represents a high-stress decision with possible severe consequences if done inaccurately.
- The information sources are widely distributed throughout the environment.

***Mitigating factors:***

- None.

*Task Pacing and Timing*—All tasks in this segment are forced-paced because the subject driver is limited in time because new gaps are continuously appearing and requiring evaluation. This situation forces the driver back to task 1.4.1, a task that is repeated until a safe gap is finally identified, and then the driver is limited in time because the gap is rapidly approaching and the decision to turn must be completed before the lead safe-gap vehicle arrives at the intersection.

Regarding the task ordering, the tasks are all concurrent because the driver must repeatedly cycle between evaluating new gaps as they become visible (task 1.4.1) and maintaining a current assessment of the situation (tasks 1.4.2 through 1.4.4).

### *Scenario 1, Segment 5, Execute Turn*

The *Execute Turn* segment involves the actions related to initiating and completing the left turn. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 14 and the scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 10 and table 15.

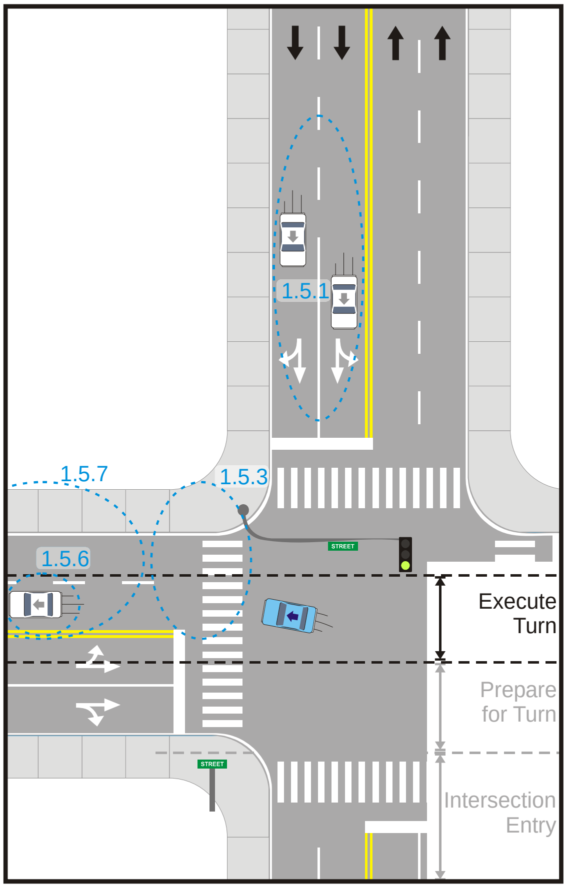
**Table 14. Scenario 1—Left Turn on Green Light *Execute Turn* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 1.5.1 Accelerate to initiate turn. | Visually monitor oncoming traffic. | **5** | Determine that acceleration is sufficient to get vehicle through the gap in oncoming traffic. | **6** | Accelerate at necessary rate. Head and eye movements to view oncoming traffic. | **3** |
| 1.5.2 Steer into turn. | View turn path. | **3** | Determine that vehicle trajectory and lane position are appropriate. | **6** | Steer to the left and make necessary adjustments to stay in lane. | **3** |
| 1.5.3 Check for hazards in turn path. | Visually scan turn path to the left (especially crosswalk). | **7** | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | **4** | Head and eye movements to view left-turn path. | **1** |
| 1.5.4 Continue accelerating up to speed. | Visually observe roadway or lead vehicle. | **3** | Determine when traveling speed reached. | **2** | Accelerate at necessary rate. Head and eye movements for viewing. | **3** |
| 1.5.5 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 1.5.6 Maintain safe distance from accelerating lead vehicle. | Visually assess distance and relative speed of lead vehicle. | **4** | Determine if lead-vehicle trajectory is safe.* | **5** | Decrease acceleration if necessary. Head and eye movements to view lead vehicle. | **3** |
| 1.5.7 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |

***** Difficulty in this subtask is increased by a value of 1 because the lead vehicle's speed is changing.

Note that the perceptual and cognitive subtasks associated with task 1.5.1 (*accelerate to initiate turn*) likely represent a worst case situation for accelerating into the turn. More specifically, if the actual gap in oncoming traffic is quite large, drivers may not need to verify that they will clear the oncoming traffic. In contrast, task 1.5.1 probably represents a situation where the gap may be in the uncomfortable range of what drivers are willing to accept, which forces them to accelerate a little quicker than usual and confirm that they are going fast enough to clear the oncoming traffic. Also, task 1.5.4 (*continue accelerating up to speed*) is simply a continuation of task 1.5.1 in the new lane, except that the difficulty associated with crossing oncoming traffic is gone. Finally, the workload value of the task 1.5.5 (*maintain safe distance from accelerating lead vehicle*) cognitive element was increased to reflect the increased difficulty of assessing the relative speed of the lead vehicle whose speed is changing.

**Scenario 1, Segment 5 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 10. Scenario 1—Left Turn on Green Light *Execute Turn* segment scenario diagram.**

**Table 15. Scenario 1—Left Turn on Green Light *Execute Turn* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe | |
|---|---|---|
| **1.5 Execute Turn** | Time<br>*Start* → | *End* |
| 1.5.1 Accelerate to initiate turn. | F | |
| 1.5.2 Steer into turn. | F | |
| 1.5.3 Check for hazards in turn path. | F | |
| 1.5.4 Continue accelerating up to speed. | | S |
| 1.5.5 Maintain safe lane position. | | F |
| 1.5.6 Maintain safe distance from accelerating lead vehicle | | S |
| 1.5.7 Check surround for unsafe situations. | | S |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 1.5.1, 1.5.2, and 1.5.3 involve high cognitive (1.5.1 and 1.5.2) or perceptual (1.5.3) workload.
- Some of the more difficult tasks are also forced-paced.
- The initial turning phase of this segment is a high-stress situation with possible severe consequences if conducted improperly.

***Mitigating factors:***

- Several tasks are routine, automatic activities.

*Task Pacing and Timing*—The tasks associated with accelerating and making the left turn (tasks 1.5.1, 1.5.2, and 1.5.3) are forced-paced because they must be accomplished during the brief time that the vehicle is turning and oncoming vehicles are rapidly approaching the exposed subject vehicle. Also, task 1.5.5 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving.

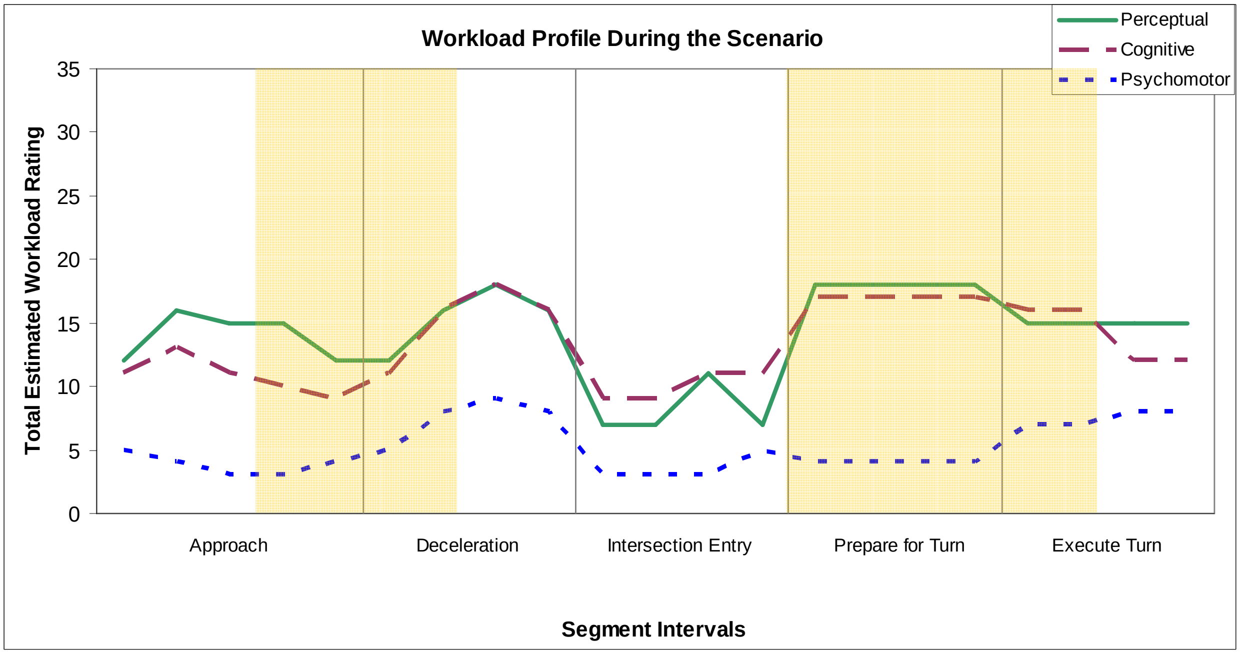
Regarding the task ordering, tasks 1.51 through 1.5.3 are concurrent, as are tasks 1.5.4 through 1.5.7.

**Scenario-Wide Analysis**

To help identify potential information processing bottlenecks in this scenario, workload estimates from all segments were combined into a single scenario-wide workload profile that provides a general indication of where the areas of high workload demands are likely to be.

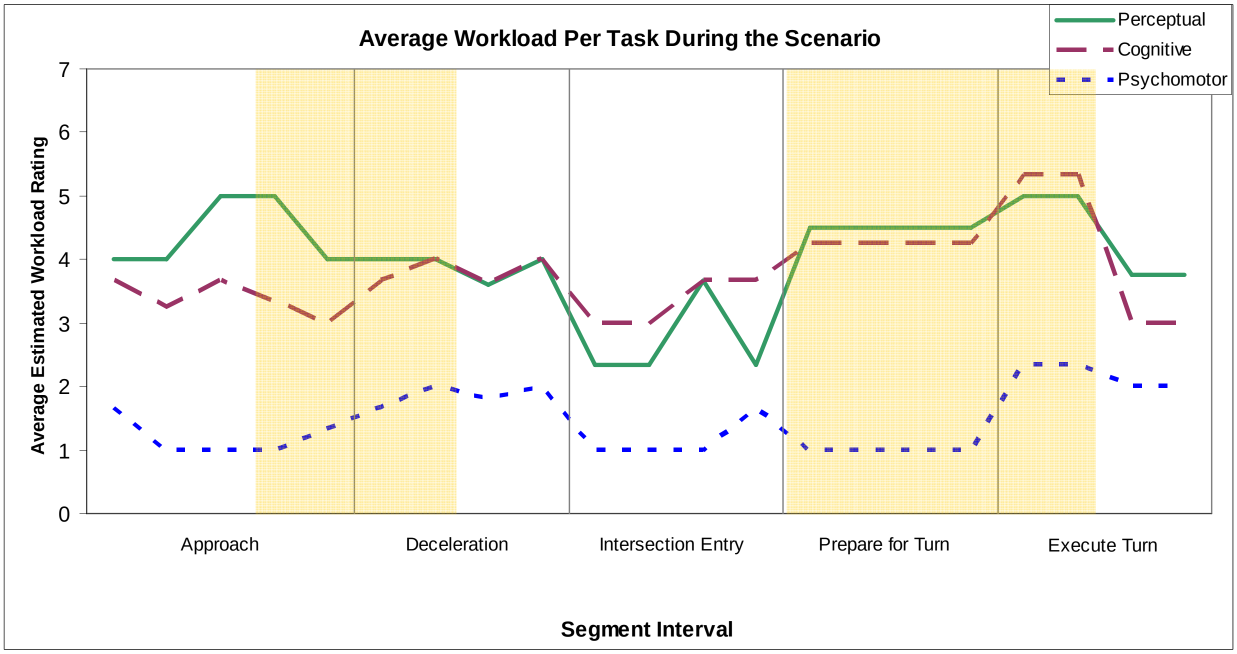
Figure 11 shows the summed workload estimates (shown separately for each information processing subtask) in each segment interval for the entire scenario. Also, the intervals in which key tasks are forced-paced are shaded in orange. As indicated by figure 11, the workload peaks for the perceptual subtasks occur during the *Approach*, *Deceleration*, and *Prepare to Turn* segments, whereas the peaks for the cognitive subtasks occur during the *Deceleration* and *Prepare to Turn* segments. The highest psychomotor workload demands also occur during the *Deceleration* segment.

Figure 12 indicates that for perceptual subtasks, relative peaks occur during the *Approach* and *Execute Turn* segments, whereas for the cognitive subtasks, the average workload estimates are slightly higher during the *Prepare to Turn* and *Execute Turn* segments.




Note: Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph shows the overall level of workload associated with a segment.

**Figure 11. Scenario 1—Left Turn on Green Light total estimated workload ratings for all tasks in each segment.**




Note: Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph generally represents the overall level of difficulty associated with the tasks in a segment.

**Figure 12. Scenario 1—Left Turn on Green Light average estimated workload ratings per task for each scenario segment.**

### *Information Processing Bottlenecks*

Information about the combined and average workload ratings, pacing of key tasks, and nature of bottlenecks for each segment is provided in table 16. Only information about potential problems is listed. Blank cells indicate that no substantive issues occurred for a particular segment or cell. Following the table is a list of key information processing bottlenecks identified in each of the segments.

**Table 16. Scenario 1—Left Turn on Green Light combined and average workload ratings, pacing of key tasks, and nature of bottlenecks that indicate potential problems for each scenario segment.**

| Segment | Combined Workload | Average Workload | Pacing of Key Tasks | Nature of Bottlenecks |
|---|---|---|---|---|
| *Approach* | Moderate perceptual workload. | High perceptual workload. | Forced-pacing of key tasks. | Frequent perceptual tasks involving scanning or reading. |
| *Deceleration* | Moderate perceptual and cognitive workload. | – | – | Concurrent and continuous conduct of several demanding cognitive tasks involving either evaluation or judgment of single or multiple factors. |
| *Intersection Entry* | – | – | – | – |
| *Prepare for Turn* | Moderate perceptual and cognitive workload. | High perceptual and cognitive workload. | Forced-pacing of all tasks. | Concurrent and continuous conduct of several high-stress and demanding perceptual and cognitive subtasks under time pressure. The information sources are widely distributed throughout the environment. |
| *Execute Turn* | Moderate perceptual and cognitive workload. | High perceptual and cognitive workload. | – | Concurrent and continuous conduct of several high-stress and demanding perceptual and cognitive subtasks under time pressure. |

*Approach* nature of bottleneck: Visual demands:

- Moderate combined and high average perceptual subtask workload involves some overlapping visual scanning and reading tasks. The difficulty of the activities in this segment is increased by the forced-pacing of the task that involves identifying the intersection as the correct turn intersection.

*Deceleration* nature of bottleneck: Several concurrent tasks*:*

- Combined workload is moderate for perceptual and cognitive subtasks; however, this level of workload is offset by the self-pacing of most of these tasks.

*Prepare for Turn* nature of bottleneck: Concurrent high workload, high-stress tasks under time pressure:

- There is moderate combined and high average perceptual and cognitive subtask workload involving continuous and concurrent tasks of moderate and high workload. These are also high-stress tasks that must be performed under time pressure, and they require information sampling that is widely distributed in the environment.

*Execute Turn* nature of bottleneck: Concurrent high workload, high-stress tasks under time pressure:

- The initial phase of this segment is somewhat of a continuation of the previous segment. Moderate combined and high average perceptual and cognitive subtask workload involves continuous and concurrent tasks of moderate and high workload. In addition, these initial tasks are high stress and must be performed under time pressure.

## SCENARIO 2—LEFT TURN ON YELLOW LIGHT

### Description

This scenario involves a vehicle making a left turn on a yellow light. Figure 13 shows the scenario diagram and provides additional details regarding the scenario. Briefly described, this scenario involves the subject driver identifying the intersection as the turn location, then decelerating. As the decelerating subject vehicle nears the intersection, the traffic light turns yellow. With no leading traffic and with the subject vehicle close enough to the intersection to go, the vehicle enters the intersection after determining that it is safe to do so and proceeds with the turn. The alternative scenario in which the traffic signal turns yellow while the driver is established in the intersection and waiting for a gap in traffic is probably more common because drivers spend more time in this phase; however, this situation was not investigated because it is nearly identical to scenario 1 with the exception that the onset of the yellow light simplifies the task by stopping oncoming traffic.

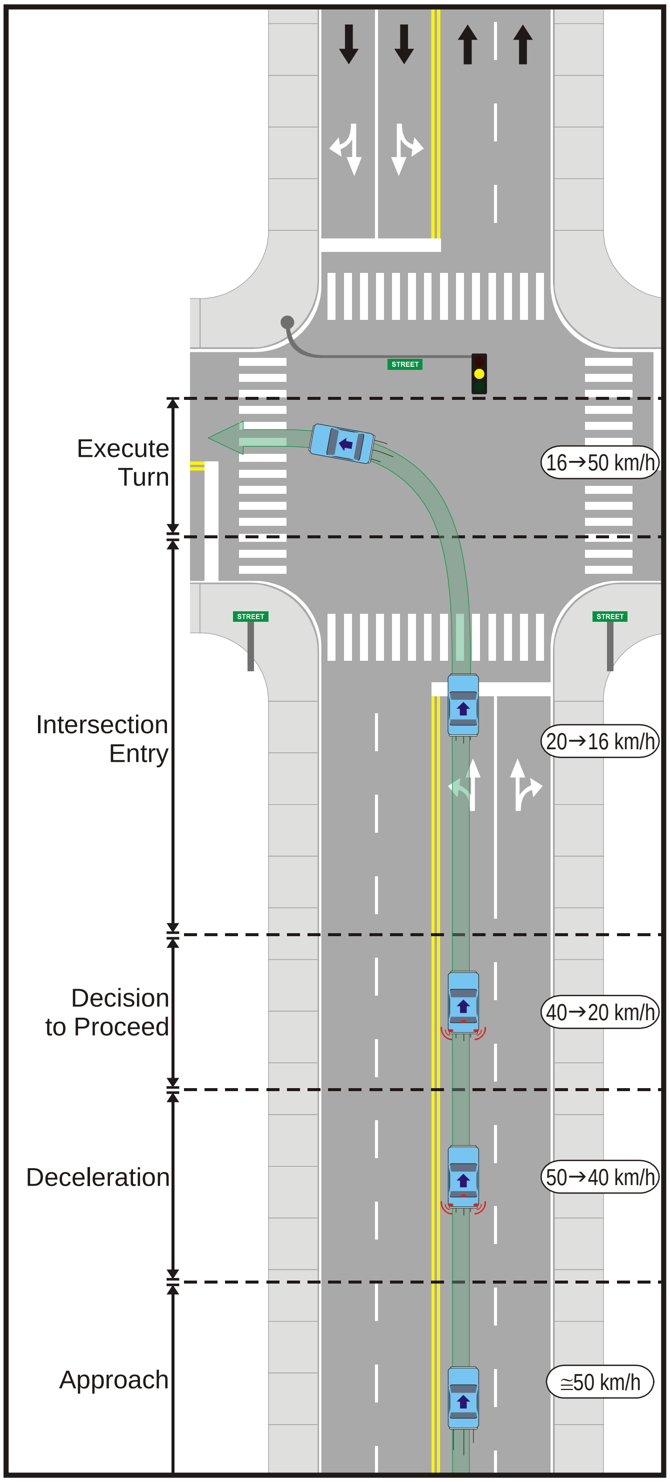
This scenario was divided into five segments (*Approach*, *Deceleration*, *Decision to Proceed*, *Intersection Entry*, and *Execute Turn*). The primary bases for parsing the scenario into these particular segments were that each segment had a different overall driving goal and most segments had different speed characteristics (table 17).

**Table 17. Scenario 2—Left Turn on Yellow Light driving objectives and speed characteristics as basis for each scenario segment partitioning.**

| Segment | Driving Objectives | Speed Characteristics |
|---|---|---|
| Approach | Identify upcoming intersection as the location of the turn. | Traveling at full speed. |
| Deceleration | Slow to turning speed/stop. | Controlled deceleration. |
| Decision to Proceed | Determine if there is sufficient time to turn and whether it is safe to do so. | Traveling at reduced speed, possibly decelerating. |
| Intersection entry | Get into position to turn. | Traveling at a slow speed, possibly decelerating. |
| Execute turn | Make the turn. | Turning and accelerating up to speed. |

The crash data associated with this scenario are basically the same as in scenario 1 (*Left Turn on Green Light*). In particular, the most common type of crash (involving 76 percent of crashes) in this scenario involves turning vehicles being struck by an oncoming vehicle,[20] which suggests that the activities preceding the turn (*Intersection Entry Segment* in this scenario) are the most challenging for drivers. The most common causal crash factors (in order of prevalence) include misjudging the gap, looking but not seeing oncoming traffic, view obstructed by intervening vehicles, and other vehicle violations.[20, 21] If only incidents in which the subject vehicle remains in motion before turning are considered (same as the current scenario), then the primary causal factors are misjudging the gap, looking but not seeing oncoming traffic, and violation of signal by the principle other vehicle (POV).[20] One point worth noting is that in more than two-thirds of the recorded cases, the subject vehicle was in motion before turning (rather than stopping first), which likely reflects the fact that less time is available to make judgments about whether or not it is safe to turn. Figure 13 shows the scenario diagram and details.

**Scenario 2 Diagram**




- Segments are demarked by dotted lines.
- Approximate speed in km/h is indicated on the right.

**Note: Illustration dimensions and vehicle positions are not to scale.**

**Scenario Details**

**Activity**:
Left Turn on a Yellow Light

**Scenario Segments:**
- Approach
- Deceleration
- Decision to proceed
- Intersection entry
- Execute turn

**Intersection Configuration**:
Four-lane urban signalized intersection *without* a dedicated left-turn lane or a left-turn signal.

**Traffic Volume:**
Moderate (driving speeds are at speed limit and other lead/following/adjacent vehicles are present).

**Assumptions/Complicating Factors**:
- There is no dedicated left-turn lane or turn signal.
- The subject vehicle is not following any vehicles, but is being followed by another vehicle.
- The turn intersection is familiar to the subject vehicle driver.
- The signal turns yellow while the driver is just past the dilemma zone.
- There is oncoming traffic that decelerates rapidly to a stop once the light turns yellow.
- No lane change is required to get into the turning lane.
- Visibility of oncoming traffic is not blocked by intervening vehicles.

**Figure 13. Scenario 2—Left Turn on Yellow Light diagram, details, and assumptions.**

Several assumptions were made regarding the situational aspects of the scenario. The justifications for these are summarized in figure 13 and more fully described in table 18.

**Table 18. Scenario 2—Left Turn on Yellow Light assumptions and corresponding justifications.**

| Assumption | Justification |
|---|---|
| There is no dedicated left-turn lane or turn signal. | Not including these items makes the task more difficult. |
| The subject vehicle is not following any vehicles but is being followed by another vehicle. | A lead vehicle was not included because it allows the left turn to be taken without the subject vehicle first coming to a stop. This situation also limits the time available to determine if it is safe to turn. |
| The turn intersection is familiar to the subject vehicle driver. | The driver merely has to recognize the intersection as the correct turn intersection, which provides some variation from other scenarios. |
| The signal turns yellow while the driver is just past the dilemma zone. | This situation increases the difficulty of the decision stage, while making it necessary to proceed with the turn. |
| There is oncoming traffic that decelerates rapidly to a stop once the light turns yellow. | This situation increases the difficulty of judging the safety of the turn, but still allows the turn to be made without stopping. |
| No lane change is required to get into the turning lane. | Although lane changes are common in turning situations, lane changes were left out to simplify segmentation. |
| Visibility of oncoming traffic is not blocked by intervening vehicles. | This element was not included because other research suggests that driver responses to this situation are complex and vary widely in ways that are impractical to model.(22) |

## Scenario Timeline

An approximate timeline showing the key temporal milestones for scenario 2 was calculated based on vehicle kinematics (figure 14). These milestones were used to make judgments about the pacing of tasks within segments, in addition to providing a basis for the overall sequencing of certain tasks. Some segments included an interval with a variable time component, which represented intervals that were either long enough to effectively provide unlimited time to perform tasks or of a duration that was determined external to vehicle kinematic factors (e.g., waiting for lead vehicle to turn).

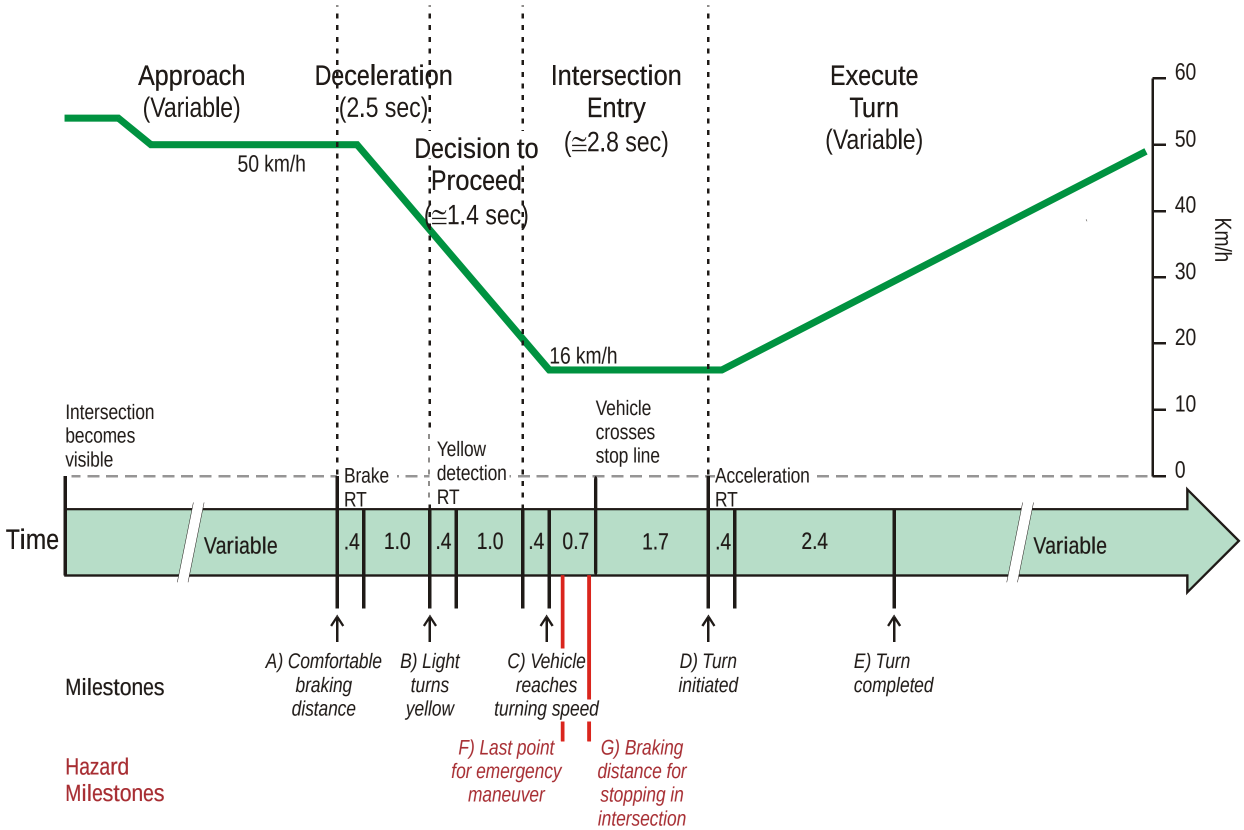



**Figure 14. Scenario 2—Left Turn on Yellow Light**
**timeline depicting key segment phases duration and event/task milestones.**

Note that the yellow light onset time was arbitrary, but nevertheless important, because it affects the allocation of tasks within segments and the time available to perform some of those tasks. A primary objective in setting the yellow onset time was to have the light change when it was not safe for the subject vehicle to stop (which works out to be just after the braking distance in this scenario). Another consideration was that the light should not change to red until after the turn was initiated (start of *Execute Turn* segment), so that the subject driver would still be required to check for—and need to be able to stop in response to—oncoming traffic crossing on a late yellow light. Thus, a yellow onset time of 2.5 sec after the start of the *Deceleration* segment (and exactly 4 sec before the *Execute Turn* segment) was chosen because it maximizes the time available to perform the tasks that need to be completed before the start of the *Execute Turn* segment, while still meeting the other requirements.

### Task Analysis Table

The results of the task analysis, organized by scenario segment, are shown in the task analysis table for scenario 2 (table 19). The task analysis results are duplicated for individual segments in the segment analyses tables in the next sections, which also contain additional discussions about the organization and content of the tasks and information processing subtasks.

**Table 19. Scenario 2—Left Turn on Yellow Light task analysis table.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **2.1 Approach** | | | |
| 2.1.1. Maintain safe lane position. | Visually monitor roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 2.1.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 2.1.3. Decelerate. | Visually assess distance to intersection. | Determine when vehicle is close enough to intersection to begin deceleration. | Coast (foot off accelerator) and/or gentle braking. |
| 2.1.4. Identify intersection as correct turn intersection. | View visual scene for indicator landmarks or street signs. | Recognize familiar intersection as correct turn intersection. | Head and eye movements for scanning. |
| 2.1.5. Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location, etc. | Determine if any nonroutine actions are required. | Head and eye movements for scanning. |
| 2.1.6. Activate turn signal. | Visually assess distance to intersection. | Determine if vehicle is close enough to start signaling. | Activate turn signal control. |
| 2.1.7. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 2.1.8. Determine if the light is about to change. | Scan visual scene for key cues (e.g., pedestrian signal). | Determine if cues suggest that the light will soon change. | Head and eye movements for scanning. |
| **2.2. Deceleration** | | | |
| 2.2.1. Maintain safe lane position. | Visually monitor roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 2.2.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 2.2.3. Begin deceleration. | Visually assess distance to intersection. | Determine when vehicle is close enough to intersection to begin deceleration. | Coast (foot off accelerator) and/or initiate braking. |
| 2.2.4. Observe vehicle deceleration trajectory. | Visually assess distance to intersection. | Determine that deceleration is sufficient for slowing to turning speed at the intersection. | Make necessary adjustments to deceleration rate. |

**Table 19. Scenario 2—Left Turn on Yellow Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **2.2 Deceleration, *continued*** | | | |
| 2.2.5. Maintain safe distance from decelerating following vehicle. | Visually assess distance and relative speed of following vehicle. | Determine if following-vehicle closing trajectory is safe. | Reduce deceleration if necessary.<br>Head and eye movements to observe rearview mirror. |
| *Note: The light is assumed to turn yellow at this point (before Segment 3).* | | | |
| **2.3. Decision to Proceed** | | | |
| 2.3.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 2.3.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 2.3.3. Observe vehicle deceleration trajectory. | Visually assess distance to intersection. | Determine that deceleration is sufficient for slowing to turning speed at the intersection. | Make necessary adjustments to deceleration rate. |
| 2.3.4. Maintain safe distance from decelerating following vehicle. | Visually assess distance and relative speed of following vehicle. | Determine if following-vehicle closing trajectory is safe. | Reduce deceleration if necessary.<br>Head and eye movements to observe rearview mirror. |
| 2.3.5. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 2.3.6. Determine if stopping will conflict with following vehicle. | Visually assess trajectory of following vehicle. | Determine whether following vehicle is too close or moving too fast to stop safely. | Head and eye movements to view rearview mirror. |
| 2.3.7. Determine if stop can be made before intersection. | Visually assess distance to the intersection. | Based on current speed, determine if it is possible to stop safely. | Head and eye movements to view intersection. |

**Table 19. Scenario 2—Left Turn on Yellow Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **2.4. Intersection Entry** | | | |
| 2.4.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 2.4.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 2.4.3. Decelerate to turning speed. | Visually assess distance to intersection. | Determine that deceleration is sufficient for slowing to turning speed or stopping in intersection. | Coast (foot off accelerator) and/or continue gentle braking. |
| 2.4.4. Check for conflict with following vehicle. | Visually assess trajectory of following vehicle. | Determine if distance and speed of following vehicle indicate potential conflict. | Head and eye movements to observe rearview mirror. |
| 2.4.5. Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | Determine if crossing vehicles are stopped or will stop in time. | Head and eye movements for observing cross traffic. |
| 2.4.6. Confirm that oncoming vehicles are stopping. | Visually observe oncoming traffic. | Determine that oncoming vehicle speed is decreasing fast enough to indicate stopping. Look for signals from drivers that they will not stop (flashing headlights). | Head and eye movements to view oncoming traffic. |
| 2.4.7. Check for hazards in turn path. | Visually scan turn path to the left (especially crosswalk). | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | Head and eye movements to view left-turn path. |
| 2.4.8. Continue into intersection. | Visually observe intersection. | Determine when vehicle is in appropriate position for turning. | Accelerate and/or decelerate as needed. |

**Table 19. Scenario 2—Left Turn on Yellow Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **2.5. Execute Turn** | | | |
| 2.5.1. Accelerate to initiate turn. | View roadway ahead. | Determine that acceleration is sufficient to get vehicle through the intersection in a timely manner. | Accelerate at necessary rate.<br>Head and eye movements to view roadway. |
| 2.5.2. Steer into turn. | View turn path. | Determine that vehicle trajectory and lane position are appropriate. | Steer to the left and make necessary adjustments to stay in lane. |
| 2.5.3. Check for hazards in turn path. | Visually scan turn path to the left (especially crosswalk). | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | Head and eye movements to view left-turn path. |
| 2.5.4. Continue accelerating up to speed. | Visually observe roadway. | Determine when traveling speed reached. | Accelerate at necessary rate.<br>Head and eye movements for viewing. |
| 2.5.5. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 2.5.6. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |

## Segment Analysis

### *Scenario 2, Segment 1, Approach*

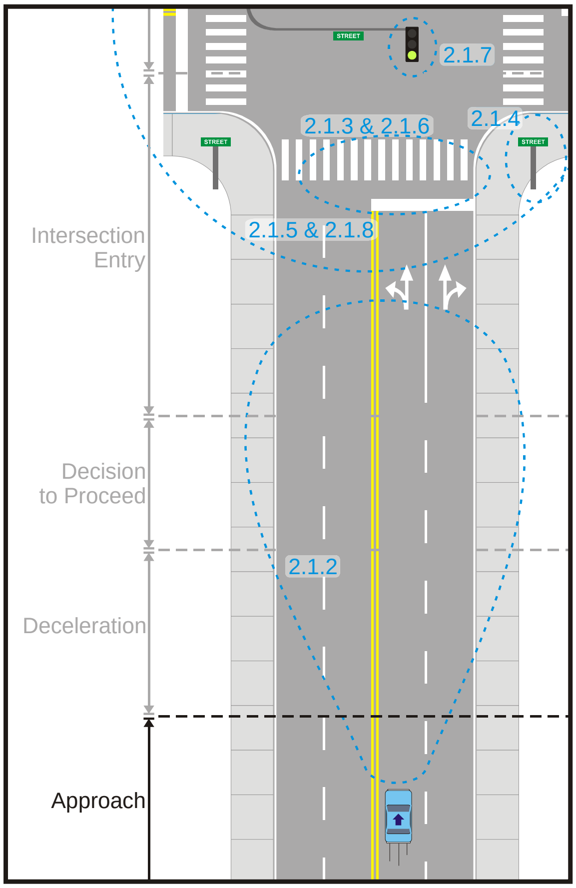
The *Approach* segment involves the subject vehicle traveling at full speed until the intersection is identified as the turn intersection, and it is the appropriate time to begin decelerating. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 20. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 15 and table 21.

**Table 20. Scenario 2—Left Turn on Yellow Light *Approach* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 2.1.1 Maintain safe lane position. | Visually monitor roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 2.1.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 2.1.3 Decelerate. | Visually assess distance to intersection. | **4** | Determine when vehicle is close enough to intersection to begin deceleration. | **6** | Coast (foot off accelerator) and/or gentle braking. | **3** |
| 2.1.4 Identify intersection as correct turn intersection. | View visual scene for indicator landmarks or street signs. | **3** | Recognize familiar intersection as correct turn intersection. | **3** | Head and eye movements for scanning. | **1** |
| 2.1.5 Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location. | **6** | Determine if any nonroutine actions are required. | **6** | Head and eye movements for scanning. | **1** |
| 2.1.6 Activate turn signal. | Visually assess distance to intersection. | **4** | Determine if vehicle is close enough to start signaling. | **4** | Activate turn signal control. | **2** |
| 2.1.7 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 2.1.8 Determine if the light is about to change. | Scan visual scene for key cues (e.g., pedestrian signal). | **7** | Determine if cues suggest that the light will soon change. | **6** | Head and eye movements for scanning. | **1** |

The deceleration that takes place in task 2.1.3 (*decelerate*) is not the same as the deceleration in the next segment, which slows the vehicle to turning speed. Instead, the task 2.1.3 deceleration is just general deceleration that should be part of any approach to an intersection.(9) Also, this segment differs from the *Approach* segment in scenario 1 in that the subject driver must identify a familiar intersection as the turn intersection (task 2.1.4). In this case, the visual and cognitive demands, in addition to the time limitations, are reduced because reading the street sign is not necessary to recognize a familiar intersection.

**Scenario 2, Segment 1 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 15. Scenario 2—Left Turn on Yellow Light *Approach* segment scenario diagram.**

**Table 21. Scenario 2—Left Turn on Yellow Light *Approach* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **2.1 Approach** | **Time** *Start* → *End* |
| 2.1.1 Maintain safe lane position. | F |
| 2.1.2 Check surround for unsafe situations. | S |
| 2.1.3 Decelerate. | S |
| 2.1.4 Identify intersection as correct turn intersection. | S |
| 2.1.5 Identify intersection characteristics. | S |
| 2.1.6 Activate turn signal. | ← S → |
| 2.1.7 Observe status of light. | ← S → |
| 2.1.8 Determine if the light is about to change. | S |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Frequent perceptual tasks involving scanning or reading in 2.1.2, 2.1.5, and 2.1.8.
- Frequent cognitive tasks involving evaluation or judgment of multiple factors in 2.1.3, 2.1.5, and 2.1.8.

***Mitigating factors:***

- Most of the tasks are self-paced.
- Many tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 2.1.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving.

The task ordering in this segment is different from the *Approach* segment from scenario 1 because task 2.1.4 (*identify intersection as the correct turn intersection*) occurs early in the segment rather than late. There are two reasons for this difference. First, because the intersection is familiar, drivers are likely to recognize it quite far away. Second, in the present segment there is no requirement to read the street sign before identifying it (which removes the time constraints). The other tasks were ordered based on logical sequence—note that the sequence has no effect on combined or average workload levels because the tasks are sequential. Finally, tasks 2.1.6 (*activate turn signal*) and 2.1.7 (*observe status of light*) can occur over a range of time.

### *Scenario 2, Segment 2, Deceleration*

The *Deceleration* segment involves the interval from when the subject vehicle begins decelerating and continues until the light turns yellow. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 22. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 16 and table 23.

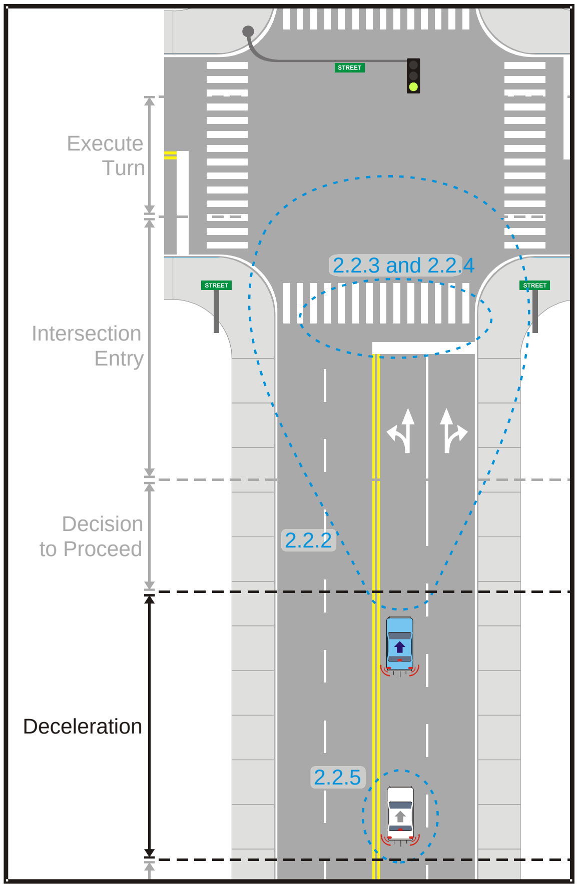
**Table 22. Scenario 2—Left Turn on Yellow Light *Deceleration* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 2.2.1 Maintain safe lane position. | Visually monitor roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 2.2.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 2.2.3 Begin deceleration. | Visually assess distance to intersection. | **4** | Determine when vehicle is close enough to intersection to begin deceleration. | **6** | Coast (foot off accelerator) and/or initiate braking. | **3** |
| 2.2.4 Observe vehicle deceleration trajectory. | Visually assess distance to intersection. | **4** | Determine that deceleration is sufficient for slowing to turning speed at the intersection. | **6** | Make necessary adjustments to deceleration rate. | **3** |
| 2.2.5 Maintain safe distance from decelerating following vehicle. | Visually assess distance and relative speed of following vehicle. | **4** | Determine if following vehicle closing trajectory is safe.* | **5** | Reduce deceleration if necessary. Head and eye movements to observe rearview mirror. | **3** |

* Difficulty in this subtask is increased by value of 1 because of degraded information.

Note that the objective of decelerating in this segment is to slow to turning speed before entering the intersection, rather than slowing to a stop as in scenario 1. Note also that the task 2.2.5 (*maintain safe distance from decelerating following vehicle*) cognitive element was treated as involving the evaluation of a single dimension (workload estimate = 4), rather than as the evaluation of multiple dimensions (workload estimate = 6) based on relative speed and distance. The reason for this lower workload estimate is that evidence suggests that drivers may evaluate time-to-arrival as a single integrated variable (*tau*) rather than as separate speed and distance components.(11) Also, the estimated workload value for the cognitive element of this task was incremented by a value of 1 because determining the closing trajectory of the following vehicle is more difficult to accomplish using the degraded indirect visual information available from the rearview mirror. Note that this task is further complicated because the following vehicle's speed is also changing; however, the difficulty level was incremented only once to reflect these factors.

**Scenario 2, Segment 2 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 16. Scenario 2—Left Turn on Yellow Light *Deceleration* segment scenario diagram.**

**Table 23. Scenario 2—Left Turn on Yellow Light *Deceleration* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **2.2 Deceleration** | Time<br>*Start* → *End* |
| 2.2.1 Maintain safe lane position. | F |
| 2.2.2. Check surround for unsafe situations. | S |
| 2.2.3 Begin deceleration. | F |
| 2.2.4 Observe vehicle deceleration trajectory. | S |
| 2.2.5 Maintain safe distance from decelerating following vehicle. | S |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 2.2.1, 2.2.2, 2.2.4, and 2.2.5.
- Several demanding cognitive tasks involving either evaluation or judgment of multiple simultaneous factors (2.2.3 and 2.2.4) or a single factor under increased difficulty (2.2.5).

***Mitigating factors:***

- Most of the difficult tasks are self-paced.
- Most tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 2.2.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Also, task 2.2.3 (*begin decelerating*) is forced-paced because the subject driver has a limited amount of time to decide to decelerate before the vehicle is too close to the stop line to permit safe or comfortable deceleration.

Regarding the task ordering, task 2.2.3 must come first because it initiates deceleration (the segment driving objective), whereas the other tasks are essentially ongoing throughout the segment.

### *Scenario 2, Segment 3, Decision to Proceed*

The *Decision to Proceed* segment spans from the time when the traffic signal turns yellow to when the driver decides to proceed, which should occur quickly thereafter. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 24. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 17 and table 25.

**Table 24. Scenario 2—Left Turn on Yellow Light *Decision to Proceed* segment tasks and information processing subtasks.**

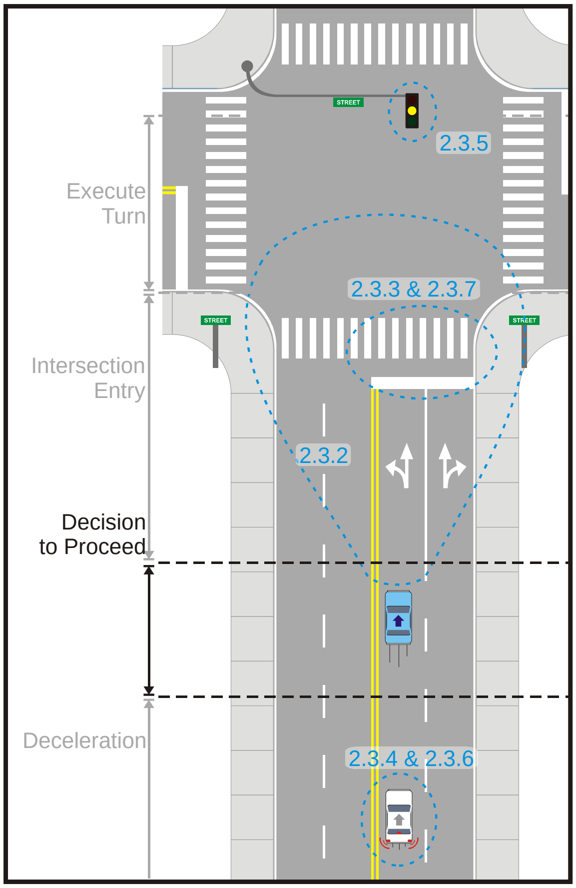
| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 2.3.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 2.3.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 2.3.3 Observe vehicle deceleration trajectory. | Visually assess distance to intersection. | **4** | Determine that deceleration is sufficient for slowing to turning speed at the intersection. | **6** | Make necessary adjustments to deceleration rate. | **3** |
| 2.3.4 Maintain safe distance from decelerating following vehicle. | Visually assess distance and relative speed of following vehicle. | **4** | Determine if following vehicle closing trajectory is safe.* | **5** | Reduce deceleration if necessary. Head and eye movements to observe rearview mirror. | **3** |
| 2.3.5 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 2.3.6 Determine if stopping will conflict with following vehicle. | Visually assess trajectory of following vehicle. | **4** | Determine if following vehicle is too close or moving too fast to stop safely.* | **5** | Head and eye movements to view rearview mirror. | **1** |
| 2.3.7 Determine if stop can be made before intersection. | Visually assess distance to the intersection. | **4** | Based on current speed, determine if it is possible to stop safely. | **6** | Head and eye movements to view intersection. | **1** |

* Difficulty in this subtask is increased by value of 1 because of degraded information.

Because the onset of the yellow light occurs while the vehicle is still decelerating, tasks 2.3.3 (*observe vehicle deceleration trajectory*) and 2.3.4 (*maintain safe distance from following vehicle*) are carried over from the previous segment. Also, the estimated workload values for tasks 2.3.4 and 2.3.6 (*determine if stopping will conflict with following vehicles*) cognitive elements were incremented by a value of 1 because judging the trajectory of the following vehicle is more difficult to do using the degraded indirect visual information from the rearview mirror.

Another point is that although according to McKnight and Adams,[9] the subject vehicle should generally check for oncoming vehicles crossing the intersection before deciding to go, this task was not included in this decision segment because the subject vehicle can stop and wait before turning after oncoming traffic has passed. Oncoming traffic is instead dealt with in the next segment (the *Intersection Entry* segment). Finally, there is no separate task defined for the actual decision about whether to proceed. This decision process is the culmination of tasks 2.3.6 and 2.3.7, and the assumption is that the decision is an implicit result of resolving these tasks.

**Scenario 2, Segment 3 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 17. Scenario 2—Left Turn on Yellow Light *Decision to Proceed* segment scenario diagram.**

**Table 25. Scenario 2—Left Turn on Yellow Light *Decision to Proceed* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **2.3 Decision to Proceed** | Time: *Start* → *End* |
| 2.3.1 Maintain safe lane position. | F |
| 2.3.2 Check surround for unsafe situations. | S |
| 2.3.3 Observe vehicle deceleration trajectory. | S |
| 2.3.4 Maintain safe distance from decelerating following vehicle. | S |
| 2.3.5 Observe status of light. | F |
| 2.3.6 Determine if stopping will conflict with following vehicles. | F |
| 2.3.7 Determine if stop can be made before intersection. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.3.6, and 2.3.7 in the latter part of the segment.
- Several demanding cognitive tasks involving either evaluation or judgment of a single factor (2.3.4 and 2.3.6) under difficult conditions or multiple simultaneous factors (2.3.3 and 2.3.7).
- Key tasks must be conducted with high time pressure.

***Mitigating factors:***

- None.

*Task Pacing and Timing*—Task 2.3.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Tasks 2.3.6 (*determine if stopping will conflict with following vehicles*) and 2.3.7 (*determine if vehicle can stop*) are forced-paced because they have to be completed as soon as possible following the onset of the yellow light in case it is necessary to stop (although that is not the case in the present scenario).

Regarding the task ordering, task 2.3.5 (*observe light*) must occur before tasks 2.3.6 and 2.3.7 because the former task initiates these latter tasks. Also, tasks 2.3.6 and 2.3.7 were depicted as occurring simultaneously when in fact they must be performed in a sequential manner. This was done because these tasks must be performed in a short time span, which may result in interference between the tasks. The other tasks are ongoing throughout the segment.

### *Scenario 2, Segment 4, Intersection Entry*

The *Intersection Entry* segment spans the time from just after the driver decides to proceed to when the subject vehicle gets into position in the intersection to make the turn. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 26. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 18 and table 27.

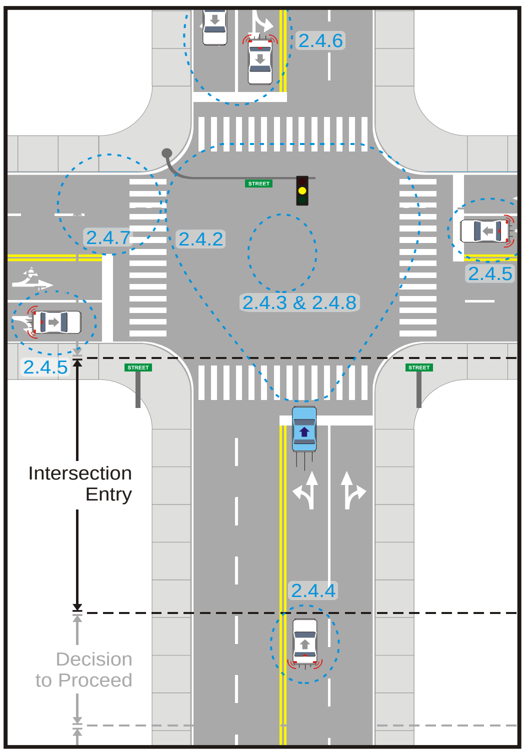
**Table 26. Scenario 2—Left Turn on Yellow Light *Intersection Entry* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 2.4.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 2.4.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 2.4.3 Decelerate to turning speed. | Visually assess distance to intersection. | **4** | Determine that deceleration is sufficient for slowing to turning speed or stopping in intersection. | **6** | Coast (foot off accelerator) and/or continue gentle braking. | **3** |
| 2.4.4 Check for conflict with following vehicle. | Visually assess trajectory of following vehicles. | **4** | Determine if distance and speed of following vehicle indicate potential conflict.* | **5** | Head and eye movements to observe rearview mirror. | **1** |
| 2.4.5 Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | **5** | Determine if crossing vehicles are stopped or will stop in time. | **4** | Head and eye movements for observing cross traffic. | **1** |
| 2.4.6 Confirm that oncoming vehicles are stopping. | Visually observe oncoming traffic. | **4** | Determine that oncoming vehicle speed is decreasing fast enough to indicate stopping. Look for signals from drivers that they will not stop (flashing headlights). | **4** | Head and eye movements to view oncoming traffic. | **1** |
| 2.4.7 Check for hazards in turn path. | Visually scan turn path to the left (especially crosswalk). | **7** | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | **4** | Head and eye movements to view left-turn path. | **1** |
| 2.4.8 Continue into intersection. | Visually observe intersection. | **1** | Determine when vehicle is in appropriate position for turning. | **4** | Accelerate and/or decelerate as needed. | **3** |

*Difficulty in this subtask is increased by a value of 1 because of degraded information.

In this segment, tasks 2.4.3 (*decelerate to turning speed*) and 2.4.8 (*continue into intersection*) are similar in that they both involve maneuvering for the turn. The difference between them is that task 2.4.3 involves general speed control as the subject vehicle approaches the intersection for turning or stopping, whereas task 2.4.8 involves more fine-tuning of position and speed in preparation for executing the turn. Also, one assumption in this segment is that cross traffic is moving and in the process of slowing to a stop, which makes task 2.4.4 more difficult because it requires the subject driver to determine if the slowing vehicles are stopping rather than simply checking whether the vehicles are stopped at the intersection. Note also that this task may be unnecessary if the following vehicle decides to stop at the light; however, if the following vehicle also tries to make it through the yellow light, the following vehicle could approach more aggressively, thus increasing the potential for a conflict. Finally, the estimated workload value for the task 2.4.4 cognitive subtask was incremented by a value of 1, because determining the trajectory of the following vehicle is more difficult to do using degraded indirect visual information from the rearview mirror.

**Scenario 2, Segment 4 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 18. Scenario 2—Left Turn on Yellow Light *Intersection Entry* segment scenario diagram.**

**Table 27. Scenario 2—Left Turn on Yellow Light *Intersection Entry* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **2.4 Intersection Entry** | **Time** *Start* → *End* |
| 2.4.1 Maintain safe lane position. | F |
| 2.4.2 Check surround for unsafe situations. | S |
| 2.4.3 Decelerate to turning speed. | F |
| 2.4.4 Check for conflict with following vehicle. | S |
| 2.4.5 Check for red-light-running cross traffic. | F |
| 2.4.6 Confirm that oncoming vehicles are stopping. | F |
| 2.4.7 Check for hazards in turn path. | F |
| 2.4.8 Continue into intersection. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 2.4.1 through 2.4.4.
- Concurrent and forced-paced conduct of 2.4.5 through 2.4.7.
- Demanding perceptual tasks involving visual scanning (2.4.2 and 2.4.7) or monitoring traffic (2.4.5).
- Information sources are widely distributed.
- High number of tasks overall.
- High time pressure.

***Mitigating factors:***

- None.

*Task Pacing and Timing*—Tasks 2.4.1 (*lane maintenance*), 2.4.3 (*decelerate to turning speed*), and 2.4.8 (*continue into intersection*) are forced-paced because they are part of the ongoing task of driving. Task 2.4.5 (*check for red-light-running traffic*) is forced-paced because the subject driver needs to identify a potential conflict while there is still enough time to take evasive action. Similarly, tasks 2.4.6 (*confirm that oncoming vehicles are stopping*) and 2.4.7 (*check for hazards in turn path*) are forced-paced because drivers must evaluate these hazards while they still have sufficient time to stop in the intersection to let the hazards pass before turning.

Regarding the task ordering, tasks 2.4.3 and 2.4.8 were allocated based on where the vehicle is in relation to the turn location. Tasks 2.4.5, 2.4.6, and 2.4.7 were depicted as occurring simultaneously when they are more likely to be performed in a sequential manner because they draw on the same visual and cognitive resources. These tasks were shown as simultaneous because given the yellow onset time, the subject driver is likely to have less than 1 sec to perform these tasks by the time the previous segments are completed, which may result in interference between the tasks, or in some tasks being skipped altogether. The other tasks are ongoing throughout the segment.

### *Scenario 2, Segment 5, Execute Turn*

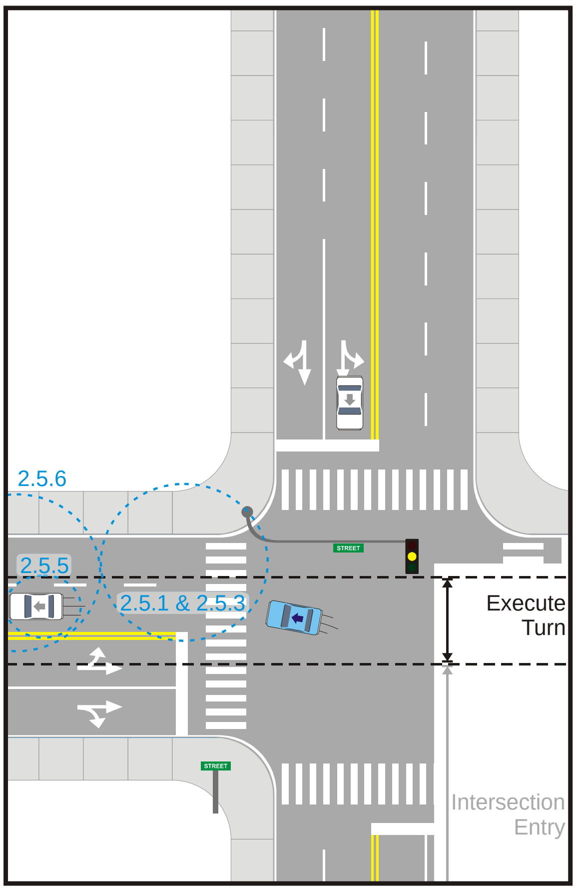
The *Execute Turn* segment involves the actions related to initiating and completing the left turn. In this scenario, the subject vehicle can safely turn without first coming to a complete stop. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 28. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 19 and table 29.

**Table 28. Scenario 2—Left Turn on Yellow Light *Execute Turn Segment* tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 2.5.1 Accelerate to initiate turn. | View roadway ahead. | **3** | Determine that acceleration is sufficient to get vehicle through the intersection in a timely manner. | **4** | Accelerate at necessary rate.<br>Head and eye movements to view roadway. | **3** |
| 2.5.2 Steer into turn. | View turn path. | **3** | Determine that vehicle trajectory and lane position are appropriate. | **6** | Steer to the left and make necessary adjustments to stay in lane. | **3** |
| 2.5.3 Check for hazards in turn path. | Visually scan turn path to the left (especially crosswalk). | **7** | Determine whether any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | **4** | Head and eye movements to view left-turn path. | **1** |
| 2.5.4 Continue accelerating up to speed. | Visually observe roadway. | **3** | Determine when traveling speed is reached. | **2** | Accelerate at necessary rate.<br>Head and eye movements for viewing. | **3** |
| 2.5.5 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 2.5.6 Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |

Note that task 2.5.1 (*accelerate to initiate turn*) has the same purpose as task 1.5.1 (*accelerate to initiate turn*) from scenario 1, but it has different perceptual and cognitive subtask workload values. The reason is that in scenario 1, oncoming vehicles are still approaching and present a possible danger that must be monitored; however, in the present scenario the subject driver is assumed to have already confirmed that oncoming vehicles are stopping. Also, task 2.5.4 (*continue accelerating up to speed*) is simply a continuation of task 2.5.1 in the new lane. Task 2.5.4 logically could have been eliminated by extending the duration of task 2.5.1; however, this task was retained to make this segment consistent with the other scenarios.

**Scenario 2, Segment 5 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 19. Scenario 2—Left Turn on Yellow Light *Execute Turn* segment scenario diagram.**

**Table 29. Scenario 2—Left Turn on Yellow Light *Execute Turn* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **2.5 Execute Turn** | **Time** *Start* → *End* |
| 2.5.1 Accelerate to initiate turn. | F |
| 2.5.2 Steer into turn. | F |
| 2.5.3 Check for hazards in turn path. | F |
| 2.5.4 Continue accelerating up to speed. | S |
| 2.5.5 Maintain safe lane position. | F |
| 2.5.6 Check surround for unsafe situations. | S |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 2.5.1, 2.5.2, and 2.5.3, involve some high cognitive (2.5.2) or perceptual (2.5.3, 2.5.6) workload.

***Mitigating factors:***

- Several tasks are routine, automatic activities.

*Task Pacing and Timing*—The tasks associated with accelerating and making the left turn (tasks 2.5.1, 2.5.2, and 2.5.3) are forced-paced because they must be accomplished during the brief time that the vehicle is turning. Also, task 2.5.5 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving.

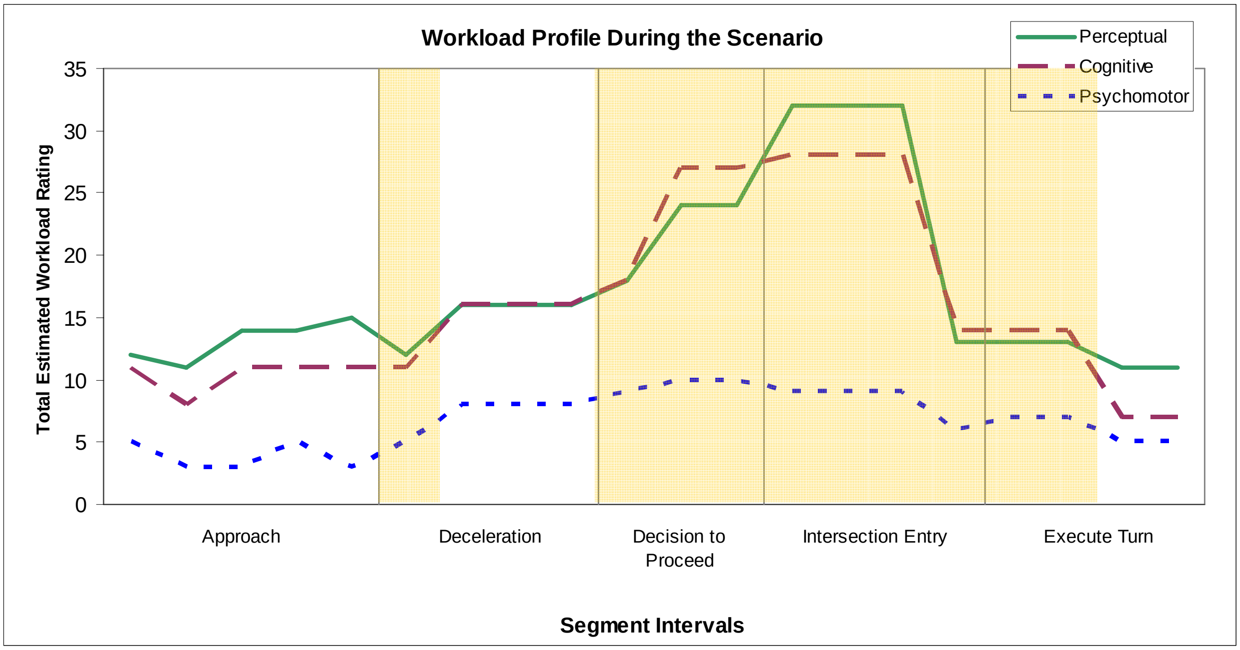
Regarding the task ordering, tasks 2.51 through 2.5.3 are concurrent, as are tasks 2.5.4 through 2.5.6.

**Scenario-Wide Analysis**

To help identify potential information processing bottlenecks in this scenario, workload estimates from all segments were combined into a single scenario-wide workload profile that provides a general indication of where the areas of high workload demands are likely to be.

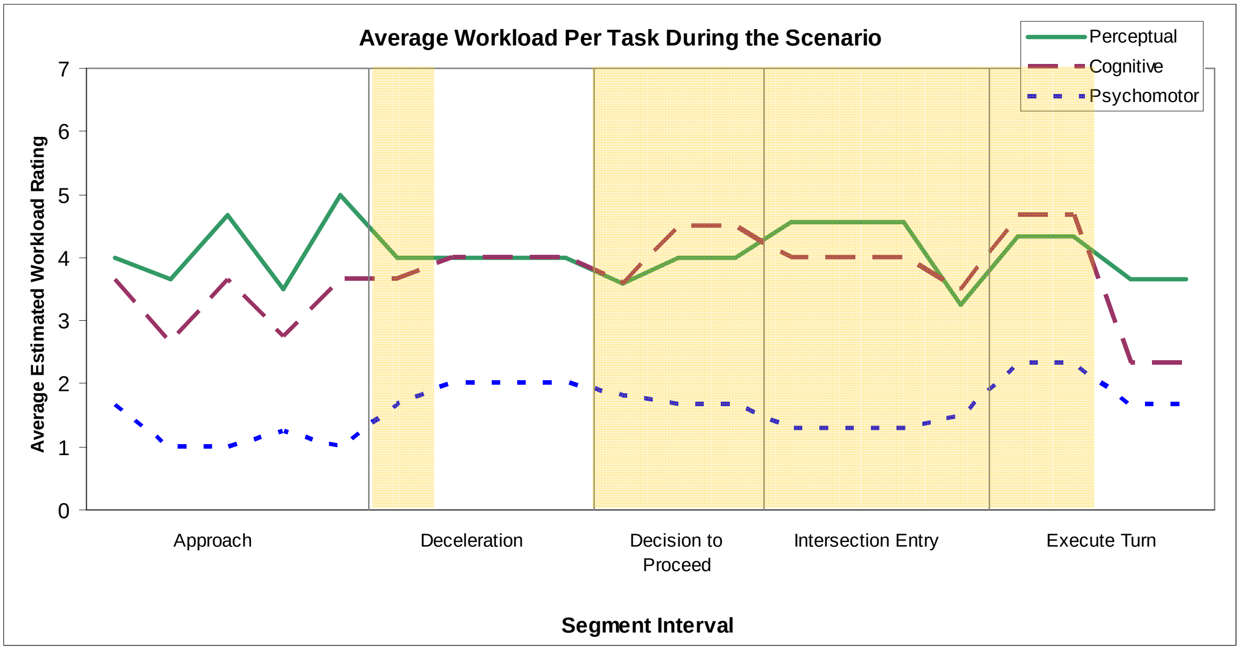
Figure 20 shows the summed workload estimates (separately for each information processing subtask) in each segment interval for the entire scenario. Also, the intervals in which key tasks are forced-paced are shaded in orange. As indicated in figure 20, the workload levels are highest for both the perceptual and cognitive elements during the *Decision to Proceed* and *Intersection Entry* segments.

Figure 21, which displays the average workload estimate of all the tasks in play during a particular segment interval, shows that the peaks during the *Decision to Proceed* and *Intersection Entry* segments in figure 20 arise from several tasks combined rather than just a few difficult tasks. This is because the average workload values in this segment are not much greater than in the other segments, although the tasks are generally high in terms of workload level. Figure 21 indicates that peaks for cognitive subtasks occur in the *Decision to Proceed* and *Execute Turn* segments, whereas the peaks for the perceptual subtasks occur during the *Approach* and *Intersection Entry* segments.




Note: Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph shows the overall level of workload associated with a segment.

**Figure 20. Scenario 2—Left Turn on Yellow Light total estimated workload ratings for all tasks in each scenario segment.**




Note: Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph generally represents the overall level of difficulty associated with the tasks in a segment.

**Figure 21. Scenario 2—Left Turn on Yellow Light average estimated workload ratings per task for each scenario segment.**

### *Information Processing Bottlenecks*

Information about the combined and average workload ratings, pacing of key tasks, and nature of bottlenecks for each segment is shown in table 30. Only information that represents potential problems is listed; blank cells indicate that no substantive issues occurred for a particular segment or cell. Following the table is a list of key information processing bottlenecks identified in each segment.

**Table 30. Scenario 2—Left Turn on Yellow Light combined and average workload ratings, pacing of key tasks, and the nature of bottlenecks that indicate potential problems for each scenario segment.**

| Segment | Combined Workload | Average Workload | Pacing of Key Tasks | Nature of Bottlenecks |
|---|---|---|---|---|
| Approach | | High perceptual workload. | | Frequent perceptual tasks involving scanning or reading, and frequent cognitive tasks involving judging multiple factors. |
| Deceleration | Moderate perceptual and cognitive workload. | | Some forced-paced tasks. | Concurrent and continuous conduct of several demanding cognitive tasks. |
| Decision to Proceed | High perceptual and cognitive workload. | High cognitive workload. | Forced-pacing of some key tasks. | Concurrent and continuous conduct of a high number of tasks, including several demanding cognitive tasks under time pressure. |
| Intersection Entry | High perceptual and cognitive workload. | High perceptual and cognitive workload. | Forced-pacing of several key tasks. | Concurrent and continuous conduct of a high number of tasks, including several perceptual and cognitive tasks with high workload, distributed information sources, and high time pressure. |
| Execute Turn | Moderate perceptual and cognitive workload. | High cognitive workload. | Forced-pacing of some key tasks. | Concurrent and continuous conduct of several tasks. |

*Approach* nature of bottleneck*:* Visual demands:

- A high average perceptual subtask workload involves some overlapping of visual scanning and reading tasks; however, this situation is offset by self-pacing of most of these tasks.

*Decision to Proceed* nature of bottleneck: High time pressure:

- A high number of demanding tasks are concurrent, and key tasks in the latter part of the segment need to be conducted under high time pressure.

*Intersection Entry* nature of bottleneck: High time pressure for several tasks:

- A high number of demanding tasks are concurrent and draw on information distributed throughout the visual scene. In addition, a relatively high number of those tasks must also be performed under high time pressure.

*Execute Turn* nature of bottleneck: Concurrent tasks:

- Concurrent, demanding cognitive subtasks take place during the initial part of the segment; however, this situation is mitigated somewhat because most of these are routine, automatic driving tasks.

## SCENARIO 3—STRAIGHT ON YELLOW LIGHT

### Description

This scenario involves the subject vehicle going straight through the intersection on a yellow light. Figure 22 shows the scenario diagram and provides additional details regarding the scenario. Briefly described, this scenario involves the driver approaching the intersection just as the light turns yellow. The driver is assumed to be in the dilemma zone where it is somewhat ambiguous as to whether the safest course of action is to stop or to go through the intersection. In this scenario, the driver does decide to proceed.

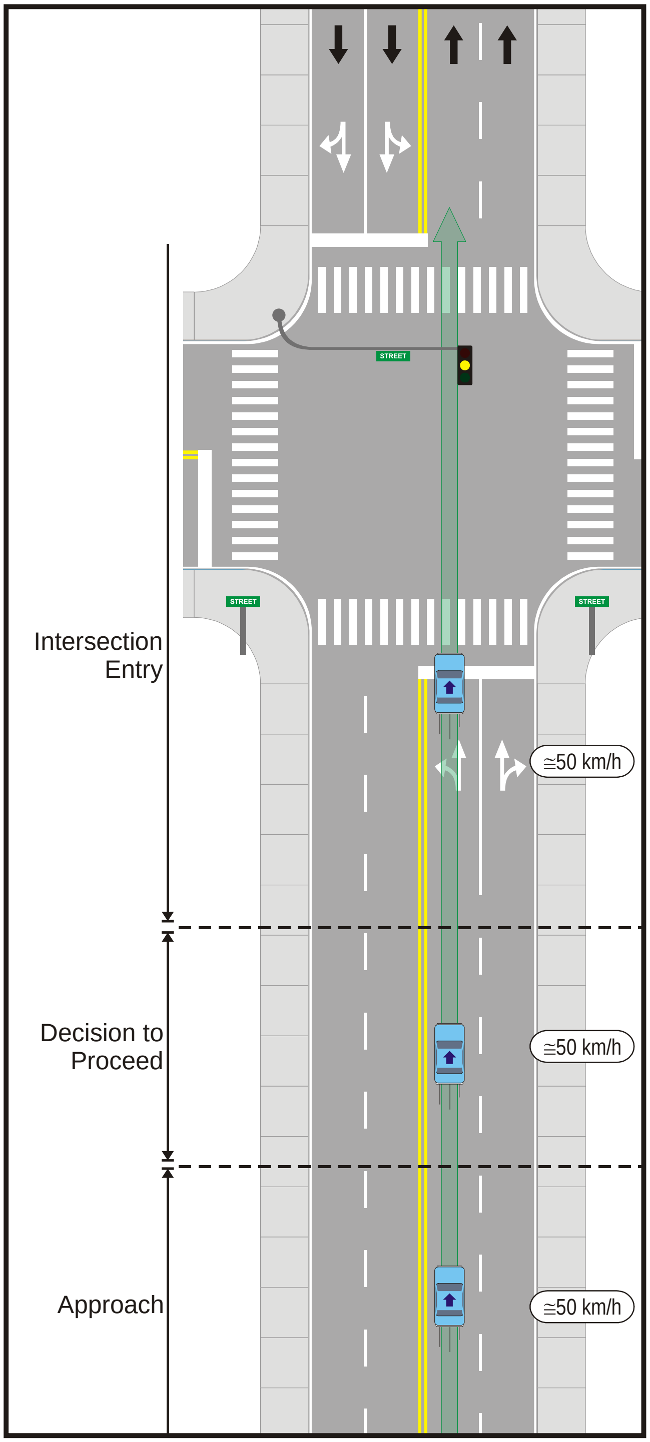
This scenario is divided into three segments (*Approach*, *Decision to Proceed*, and *Intersection Entry*). Only three segments were required in this scenario because for most of this scenario, drivers are mostly performing similar tasks related to traveling forward, with the decision to proceed briefly punctuating this process in the middle. The primary basis for parsing this scenario into these segments is that each segment had a different overall driving goal (table 31). Unlike with other scenarios, the speed of the subject vehicle does not vary greatly between segments. Figure 22 shows the diagram for scenario 3 and lists scenario 3 activities.

**Table 31. Scenario 3—Straight on Yellow Light driving objectives and speed characteristics for each scenario segment as a basis for the scenario partitioning.**

| Segment | Driving Objectives | Speed Characteristics |
|---|---|---|
| *Approach* | Gather information about the situation. | Traveling at full speed with some deceleration. |
| *Decision to Proceed* | Determine whether or not to proceed through the intersection. | Traveling near full speed. |
| *Intersection Entry* | Entering and proceeding through the intersection. | Traveling near full speed or accelerating to full speed. |

The crash data regarding this scenario indicate that the decision to proceed likely represents a source of problems for many drivers.[10] In particular, the most common contributing factors include deliberately running the signal (40 percent), either because drivers failed to obey the signal (23.1 percent) or tried to beat the signal (16.2 percent). The next most common contributing factor was driver inattention (36.4 percent). There are two explanations of why these problems are linked to the decision stage.[10] In particular, the decision stage essentially involves assessing the situation and then deciding whether it is safe to go based on that assessment. Thus, there are two ways for drivers to end up running the signal when the appropriate action is to stop: correctly assessing the situation as unsafe and then making a bad decision to go anyway, or incorrectly assessing the situation as safe (because the driver missed relevant information) and making the logical—but incorrect—decision to proceed. The latter case is similar to driver inattention, whereby drivers also fail to adequately perceive and process the necessary situational information.

**Scenario 3 Diagram**




- Segments are demarked by dotted lines.
- Approximate speed in km/h is indicated on the right.

**Note: Illustration dimensions and vehicle positions are not to scale.**

**Scenario Details**

**Activity**:
Straight on Yellow Light

**Scenario Segments:**
- Approach
- Decision to Proceed
- Intersection Entry

**Intersection Configuration**:
Four-lane urban signalized intersection *without* a dedicated left-turn lane.

**Traffic Volume:**
Moderate (driving speeds are at speed limit and other lead/following/adjacent vehicles are present).

**Assumptions/Complicating Factors**:
- The traffic signal is initially green but changes to yellow during the approach.
- The signal turns yellow while the driver is in the dilemma zone.
- The subject vehicle is following a vehicle and followed by another vehicle.
- There is oncoming traffic, but no vehicles are waiting to turn left.
- The roadway is dry.

**Figure 22. Scenario 3—Straight on Yellow Light diagram, details, and assumptions.**

Several assumptions were made regarding the situational aspects of the scenario. The justifications for these are described in table 32 and summarized in figure 22.

**Table 32. Scenario 3—Straight on Yellow Light assumptions and corresponding justifications.**

| Assumption | Justification |
|---|---|
| The signal turns yellow while the driver is in the dilemma zone. | This situation maximizes the difficulty of the decision stage. |
| The subject vehicle is following a vehicle and followed by another vehicle. | Including this extra traffic makes the decision to proceed more difficult by requiring the driver to consider additional information. |
| There is oncoming traffic, but no vehicles are waiting to turn left. | If there are left-turning vehicles, drivers should try to stop.[9] |
| The roadway is dry. | As indicated by focus group research,[22] drivers will respond differently to wet roads (e.g., making them more likely to go, or approaching the entire scenario more cautiously). Because implications on the decision to proceed are unpredictable, wet pavement is avoided. |

### Scenario Timeline

An approximate timeline showing the key temporal milestones for scenario 3 was calculated based on vehicle kinematics (figure 23). These milestones were used to make judgments about the pacing of tasks within segments and provide a basis for the overall sequencing of certain tasks. Most segments included an interval with a variable time component, which represented intervals that were either long enough to effectively provide unlimited time to perform tasks or of a duration that was determined external to vehicle kinematic factors (e.g., waiting for lead vehicle to turn).

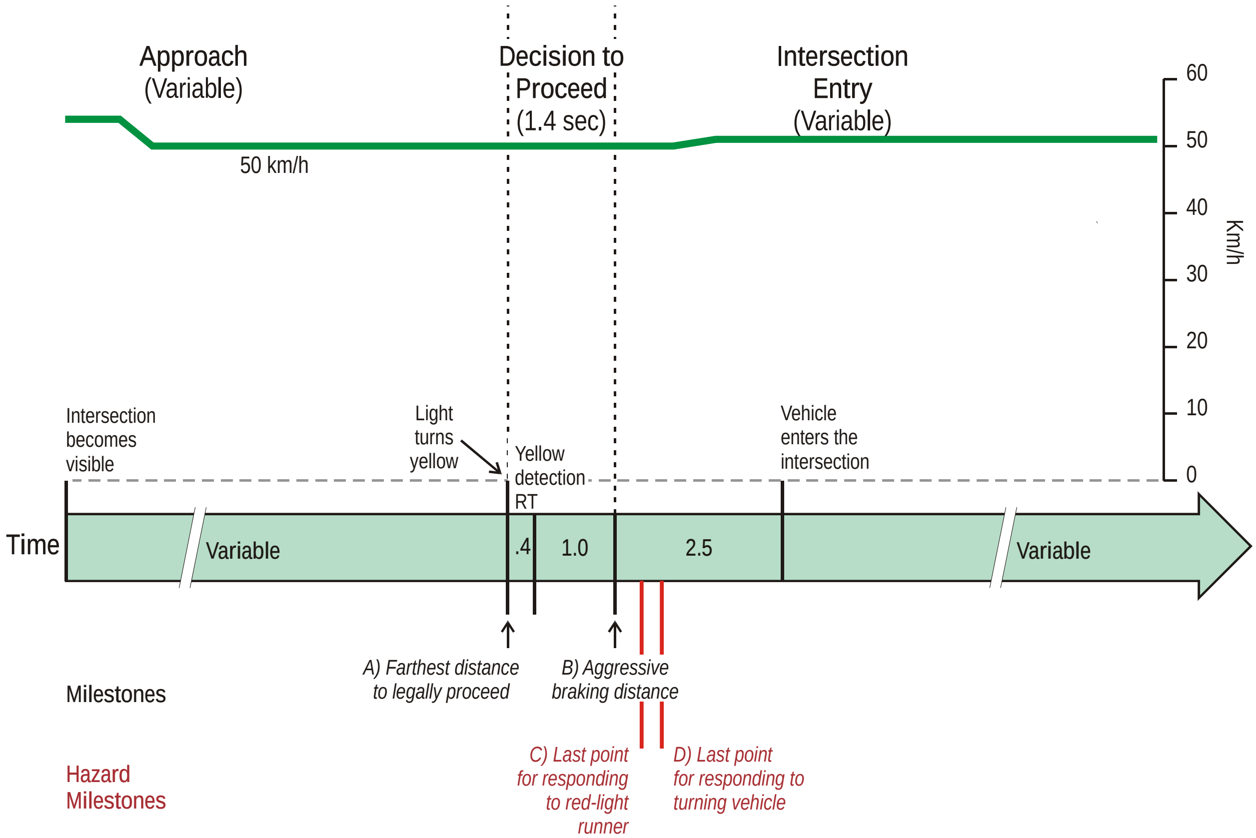



**Figure 23. Scenario 3—Straight on Yellow Light timeline depicting duration of key segment phases and event/task milestones.**

## Task Analysis Table

The results of the task analysis organized by scenario segment are shown in table 33, the task analysis table. The task analysis results are duplicated for individual segments in the segment analyses tables in the next sections, which more fully discuss the organization and content of the tasks and information processing subtasks.

**Table 33. Scenario 3—Straight on Yellow Light task analysis table.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **3.1. Approach** | | | |
| 3.1.1 Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 3.1.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 3.1.3 Maintain safe distance from lead vehicle traveling at constant speed. | Visually assess distance and relative speed of leading vehicle. | Determine if lead-vehicle trajectory is safe. | Reduce speed if necessary. Head and eye movements to view vehicle. |
| 3.1.4 Decelerate. | Visually assess distance to intersection. | Determine when vehicle is close enough to intersection to begin deceleration. | Coast (foot off accelerator) and/or gentle braking. |
| 3.1.5 Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location. | Determine if any nonroutine actions are required. | Head and eye movements for scanning. |
| 3.1.6 Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 3.1.7 Determine if the light is about to change. | Scan visual scene for key cues (e.g., pedestrian signal). | Determine if cues suggest that the light will soon change. | Head and eye movements for scanning. |
| **3.2. Decision to Proceed** | | | |
| 3.2.1 Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 3.2.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 3.2.3 Maintain safe distance from lead vehicle traveling at constant speed. | Visually assess distance and relative speed of leading vehicle. | Determine if lead-vehicle trajectory is safe. | Reduce speed if necessary. Head and eye movements to view vehicle. |
| 3.2.4 Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 3.2.5 Determine if lead vehicle is stopping or proceeding through intersection. | Visually determine if lead vehicle is decelerating. | Decide if deceleration is sufficient to indicate that the vehicle is stopping. | Head and eye movements to view lead vehicle. |

**Table 33. Scenario 3—Straight on Yellow Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **3.2. Decision to Proceed, *continued*** | | | |
| 3.2.6 Determine if stopping will conflict with following vehicle. | Visually assess trajectory of following vehicle. | Determine if following vehicle is too close or moving too fast to stop safely. | Head and eye movements to view rearview mirror. |
| 3.2.7 Determine if stop can be made before intersection. | Visually assess distance to the intersection. | Based on current speed, determine if it is possible to stop safely. | Head and eye movements to view intersection. |
| 3.2.8 Determine if oncoming vehicles are trying to turn left across path. | Look for signs of vehicle turning (turn signal, stopped in intersection). | Decide if oncoming vehicles are turning. | Head and eye movements to view oncoming vehicles. |
| **3.3. Intersection Entry** | | | |
| 3.3.1 Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 3.3.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 3.3.3 Maintain safe distance from lead vehicle traveling at constant speed. | Visually assess distance and relative speed of leading vehicle. | Determine if lead-vehicle trajectory is safe. | Reduce speed if necessary. Head and eye movements to view vehicle. |
| 3.3.4 Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | Determine if crossing vehicles are stopped or will stop in time. | Head and eye movements for observing cross traffic. |
| 3.3.5 Check for oncoming vehicle trying to turn left across path at last minute. | Look for signs of vehicle turning (turn signal, stopped in intersection). | Decide if oncoming vehicle is turning. | Head and eye movements to view oncoming vehicle. |
| 3.3.6 Accelerate to get through the intersection. | Visually observe distance to lead vehicle and intersection. | Determine if it is safe to accelerate based on distance and relative speed of lead vehicle. | Accelerate at necessary rate. |

## Segment Analysis

### *Scenario 3, Segment 1, Approach*

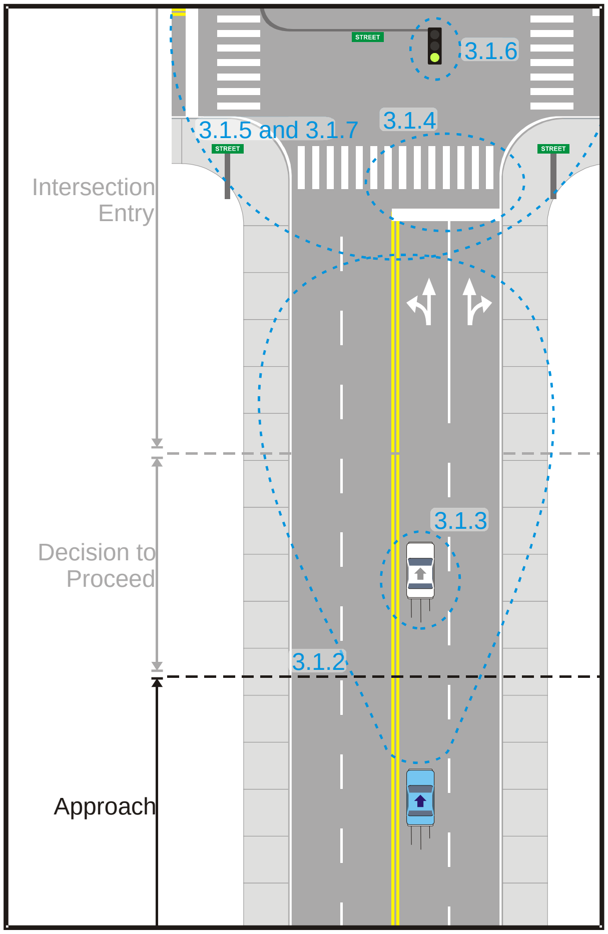
The *Approach* segment involves the subject vehicle traveling at full speed until the traffic signal turns yellow. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 34. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 24 and table 35.

**Table 34. Scenario 3—Straight on Yellow Light *Approach* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 3.1.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 3.1.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 3.1.3 Maintain safe distance from lead vehicle traveling at constant speed. | Visually assess distance and relative speed of leading vehicle. | **4** | Determine if lead-vehicle trajectory is safe. | **4** | Reduce speed if necessary. Head and eye movements to view vehicle. | **3** |
| 3.1.4 Decelerate. | Visually assess distance to intersection. | **4** | Determine when vehicle is close enough to intersection to begin deceleration. | **6** | Coast (foot off accelerator) and/or gentle braking. | **3** |
| 3.1.5 Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location. | **6** | Determine if any nonroutine actions are required. | **6** | Head and eye movements for scanning. | **1** |
| 3.1.6 Observe status of the light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 3.1.7 Determine if the light is about to change. | Scan visual scene for key cues (e.g., pedestrian signal). | **7** | Determine if multiple cues suggest that the light will soon change. | **6** | Head and eye movements for scanning. | **1** |

Task 3.1.7 (*determine if the light is about to change*) can range in difficulty based on the degree to which direct information is or is not available. For example, if a pedestrian walk signal were visible during the approach, it could make the perceptual task into a simple inspection task (workload demand = 3) rather than a potentially complicated visual search task (workload demand = 7) to identify cues distributed throughout the roadway (e.g., looking for a vehicle queue in oncoming traffic or observing pedestrian behavior). The more demanding version was selected in keeping with the overall goals of addressing the worst-case scenarios. Note also that task 3.1.6 (*observe status of the light*) is intended to reflect early viewing of the signal that is part of the process of initially assessing the situation, and not the glance that observes the light changing to yellow.

**Scenario 3, Segment 1 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 24. Scenario 3—Straight on Yellow Light *Approach* segment diagram.**

**Table 35. Scenario 3—Straight on Yellow Light *Approach* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **3.1 Approach** | **Time** *Start* → *End* |
| 3.1.1 Maintain safe lane position. | F |
| 3.1.2 Check surround for unsafe situations. | S |
| 3.1.3 Maintain safe distance from lead vehicle traveling at constant speed. | S |
| 3.1.4 Decelerate. | S |
| 3.1.5 Identify intersection characteristics. | S |
| 3.1.6 Observe status of the light. | ← S → |
| 3.1.7 Determine if the light is about to change. | S |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Frequent perceptual tasks involving scanning in 3.1.2, 3.1.5, and 3.1.7.
- Frequent cognitive tasks involving evaluation or judgment of several factors in 3.1.4, 3.1.5, and 3.1.7.

***Mitigating factors:***

- Most of the difficult tasks are self-paced.
- Many tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 3.1.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving, but the other tasks are self-paced.

Regarding the task ordering, tasks 3.1.4 through 3.1.7 are sequential and can essentially be performed in any order. The ordering chosen in this segment followed a logical sequence and was consistent with the ordering of similar tasks in the *Approach* segment in the other scenarios.

### *Scenario 3, Segment 2, Decision to Proceed*

The *Decision to Proceed* segment spans from the time that the traffic signal turns yellow to when the driver decides to proceed, which occurs within a few seconds. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 36. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 25 and table 37.

**Table 36. Scenario 3—Straight on Yellow Light segment 2 *Decision to Proceed* tasks and information processing subtasks.**

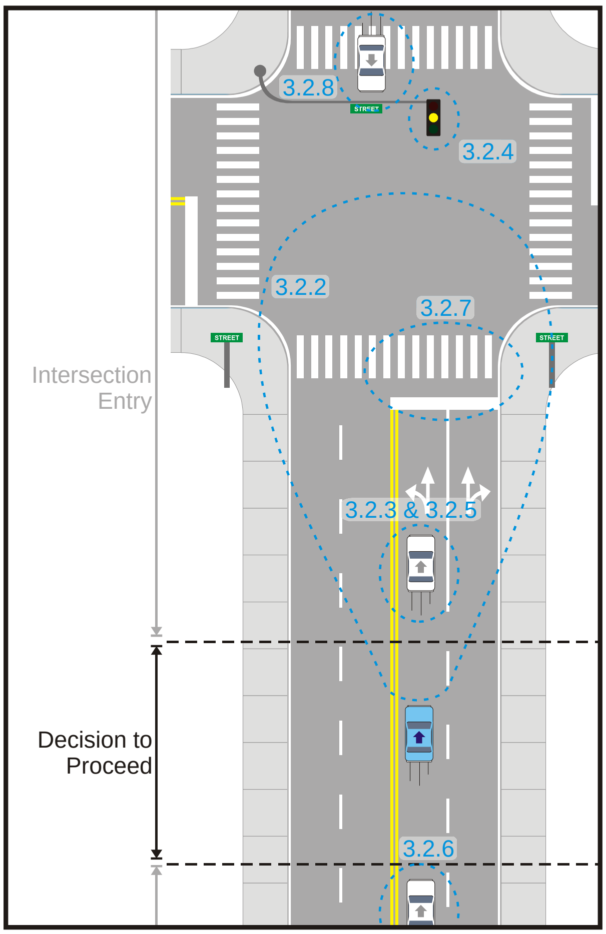
| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 3.2.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 3.2.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 3.2.3 Maintain safe distance from lead vehicle traveling at constant speed. | Visually assess distance and relative speed of lead vehicle. | **4** | Determine if lead-vehicle trajectory is safe. | **4** | Reduce speed if necessary. Head and eye movements to view vehicle. | **3** |
| 3.2.4 Observe status of the light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 3.2.5 Determine if lead vehicle is stopping or proceeding through intersection. | Visually determine if lead vehicle is decelerating. | **4** | Decide if deceleration is sufficient to indicate that the vehicle is stopping. | **4** | Head and eye movements to view lead vehicle. | **1** |
| 3.2.6 Determine if stopping will conflict with following vehicle. | Visually assess trajectory of following vehicle. | **4** | Determine if following vehicle is too close or moving too fast to stop safely.* | **5** | Head and eye movements to view rearview mirror. | **1** |
| 3.2.7 Determine if stop can be made before intersection. | Visually assess distance to the intersection. | **4** | Based on current speed, determine if it is possible to stop safely. | **6** | Head and eye movements to view intersection. | **1** |
| 3.2.8 Determine if oncoming vehicles are trying to turn left across path. | Look for signs of vehicle turning (turn signal, stopped in intersection). | **4** | Decide if oncoming vehicles are turning. | **6** | Head and eye movements to view oncoming vehicles. | **1** |

*Difficulty in this subtask is increased by a value of 1 because of degraded information.

There are several noteworthy points in this segment. The first is that the lane maintenance and hazard monitoring tasks (3.2.1 through 3.2.3) are included because even though many drivers are unlikely to perform these tasks in the relatively brief time it takes to make their decisions, they are nonetheless still required for safe driving and including these tasks emphasizes that drivers are more likely to skip these tasks. Also, the estimated workload value for task 3.2.6 (*determine if stopping will conflict with following vehicle*) cognitive subtask was incremented by a value of 1, because determining the trajectory of the following vehicle is more difficult to do using the degraded indirect visual information from the rearview mirror.

Finally, there is no separate task defined for the actual decision about whether to proceed. This decision process is the culmination of tasks 3.2.5 through 3.2.8, and the assumption is that the decision is an implicit result of resolving these tasks. The exception would be if the precursor tasks yielded contradictory decisions (e.g., the lead vehicle is stopping, but stopping will result in a conflict with the following vehicle). In this case, a separate decision task would be necessary to resolve the conflict. In the present scenario, however, the precursor tasks do not result in contradictory decisions, and these conflicts do not exist.

**Scenario 3, Segment 2 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 25. Scenario 3—Straight on Yellow Light Scenario *Decision to Proceed* segment diagram.**

**Table 37. Scenario 3—Straight on Yellow Light *Decision to Proceed* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **3.2 Decision to Proceed** | **Time** *Start* → *End* |
| 3.2.1 Maintain safe lane position. | F |
| 3.2.2 Check surround for unsafe situations. | S |
| 3.2.3 Maintain safe distance from lead vehicle traveling at constant speed. | S |
| 3.2.4 Observe status of light. | F |
| 3.2.5 Determine if lead vehicle is stopping or proceeding through intersection. | F |
| 3.2.6 Determine if stopping will conflict with following vehicle. | F |
| 3.2.7 Determine if stop can be made before intersection. | F |
| 3.2.8 Determine if oncoming vehicles are trying to turn left across path. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 3.2.1 through 3.2.3 and 3.2.5 through 3.2.8.
- Several demanding cognitive tasks involving either evaluation or judgment of single (3.2.6) factor under difficult conditions, or multiple simultaneous factors in 3.2.7 and 3.2.8.
- All tasks must be conducted within an extremely short time period.

***Mitigating factors:***

- None.

*Task Pacing and Timing*—Task 3.2.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Tasks 3.2.4 through 3.2.8 are forced-paced because they have to be completed in a very limited amount of time (approximately 1 sec in this scenario).

Regarding the task ordering, tasks 3.2.5 through 3.2.8 were depicted as occurring simultaneously when they must in fact be performed in a sequential manner. These tasks were shown this way because they must be performed in an exceptionally short time span, which may result in interference between the tasks. In addition, depicting these tasks in this way emphasizes the fact that it is unlikely that drivers are able to complete all of these tasks in the available time. Note also that the order of tasks 3.2.5 through 3.2.8 likely varies between drivers. Task 3.2.8 (*determine if oncoming vehicles are trying to turn left*) was placed at the end because drivers probably have more flexibility regarding whether to proceed based on this information than the other tasks. Although stopping for left-turn traffic is the appropriate action, failing to do so is less likely to result in a vehicle conflict than making an inappropriate decision in tasks 3.2.5 through 3.2.6.

One important point that the task analysis underscores in this scenario is that dilemma-zone situations provide limited options for drivers.[(23)] In the current example, if drivers spend more than 1 sec performing the tasks described in this segment, they only have the option of continuing through the intersection, because after 1 sec they are too close to stop comfortably before the stop line (even with aggressive values for response time and deceleration). Note that this also represents an optimal situation because the subject vehicle is assumed to be in the limited option zone region in which it is possible to either stop or legally enter the intersection. In contrast, if the vehicle is farther back and the driver takes a little longer to decide what to do, then the driver may be left with no safe or legal options. For example, if the subject vehicle is just 10 to 15 meters (m) farther back when the light turns yellow, and if the driver takes 2 sec rather than 1 sec to complete decisionmaking tasks, then the vehicle will be too close to the intersection to stop, yet too far from the intersection to enter before the light turns red without accelerating (arrival will occur more than 0.5 sec after the light turns red). Thus, this is an inherently difficult segment for drivers, not only because they have an extremely limited amount of time to perform several tasks, but they may also be limited in the types of actions they can safely or legally take.

### *Scenario 3, Segment 3, Intersection Entry*

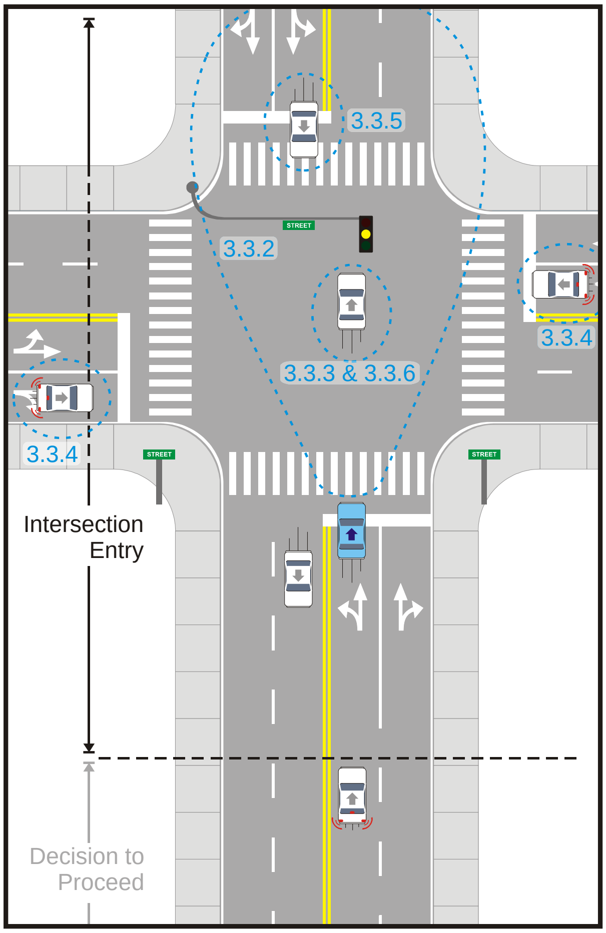
The *Intersection Entry* segment spans the interval from when the driver decides to proceed into the intersection to when the subject vehicle crosses to the other side of the intersection. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 38. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 26 and table 39.

**Table 38. Scenario 3—Straight on Yellow Light *Intersection Entry* segment of tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 3.3.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 3.3.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 3.3.3 Maintain safe distance from lead vehicle traveling at constant speed. | Visually assess distance and relative speed of leading vehicle. | **4** | Determine if lead-vehicle trajectory is safe. | **4** | Reduce speed if necessary. Head and eye movements to view vehicle. | **3** |
| 3.3.4 Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | **5** | Determine if crossing vehicles are stopped or will stop in time. | **4** | Head and eye movements for observing cross traffic. | **1** |
| 3.3.5 Check for oncoming vehicle trying to turn left across path at last minute. | Look for signs of vehicle turning (turn signal, stopped in intersection). | **4** | Decide if oncoming vehicle is turning. | **6** | Head and eye movements to view oncoming vehicle. | **1** |
| 3.3.6 Accelerate to get through the intersection. | Visually observe distance to lead vehicle and intersection. | **4** | Determine if it is safe to accelerate based on distance and relative speed of lead vehicle. | **6** | Accelerate at necessary rate. | **3** |

Several points are noteworthy in this segment. The first is that task 3.3.5 (*check for left-turning traffic*) is duplicated from the previous segment, which occurs shortly before this one. The reason for this repetition is that in the previous segment this task was a decision criterion, whereas in the present segment it acts as a safety check for hazards. Another point is that whereas task 3.3.6 (*accelerate to get through the intersection*) is not part of the McKnight and Adams task analysis(9) and may not represent the safest action, it was included based on driver focus group findings involving similar intersection scenarios. In particular, these findings indicated that many younger and middle-aged drivers would be inclined to accelerate after they have decided to go on yellow to make sure they will get through before the light turns red.(21) Also, as discussed in the previous segment, drivers that are a little farther back when the light turns yellow may not have the option of either stopping safely or making it through the intersection legally unless they accelerate. Thus, this step was included because it likely reflects the manner in which many drivers act and also provides more of a worst-case scenario in terms of driver workload demands. Finally, it was assumed that the following vehicle would stop on the yellow light, so there is no need to maintain safe distance from the following vehicle.

**Scenario 3, Segment 3 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 26. Scenario 3—Straight on Yellow Light *Intersection Entry* segment diagram.**

**Table 39. Scenario 3—Straight on Yellow Light *Intersection Entry* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **3.3 Intersection Entry** | Time: *Start* → *End* |
| 3.3.1 Maintain safe lane position. | F |
| 3.3.2 Check surround for unsafe situations. | S |
| 3.3.3 Maintain safe distance from lead vehicle traveling at constant speed. | S |
| 3.3.4 Check for red-light-running cross traffic. | F |
| 3.3.5 Check for oncoming vehicles trying to turn left across path at last minute. | F |
| 3.3.6 Accelerate to get through the intersection. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and successive visual scanning (3.3.2) and visual localization/monitoring tasks (3.3.4 and 3.3.5) that must be completed quickly.
- Multiple overlapping tasks involving moderate and high cognitive demands.
- Some critical safety-related tasks are forced-paced.

***Mitigating factors:***

- Several of the tasks are routine, automatic activities.

*Task Pacing and Timing*—Tasks 3.3.1 (*lane maintenance*) and 3.3.6 (*accelerate to get through intersection*) are forced-paced because they are part of the ongoing task of driving. Tasks 3.3.4 (*check for red-light-running traffic*) and 3.3.5 (*check for oncoming turning vehicles*) are forced-paced because they have to be completed as the vehicle is rapidly approaching the intersection.

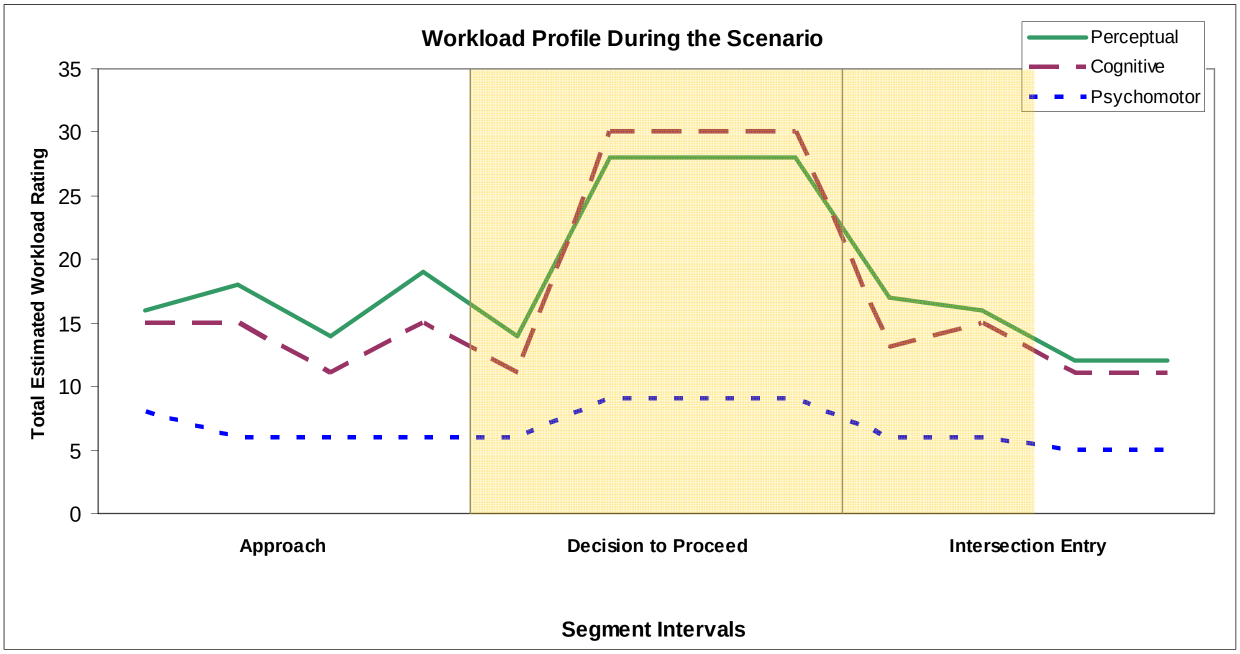
Regarding the task ordering, tasks 3.3.4 and 3.3.5 are ordered based on which one is encountered first. Also, task 3.3.6 (*accelerate through intersection*) is just a variant of task 3.3.3 (*maintain safe distance from lead vehicle*), and it is likely to follow the hazard-checking tasks.

## Scenario-Wide Analysis

To help identify potential information processing bottlenecks in this scenario, workload estimates from all the segments were combined into a single scenario-wide workload profile that provides a general indication of where the areas of high workload demands are likely to be.

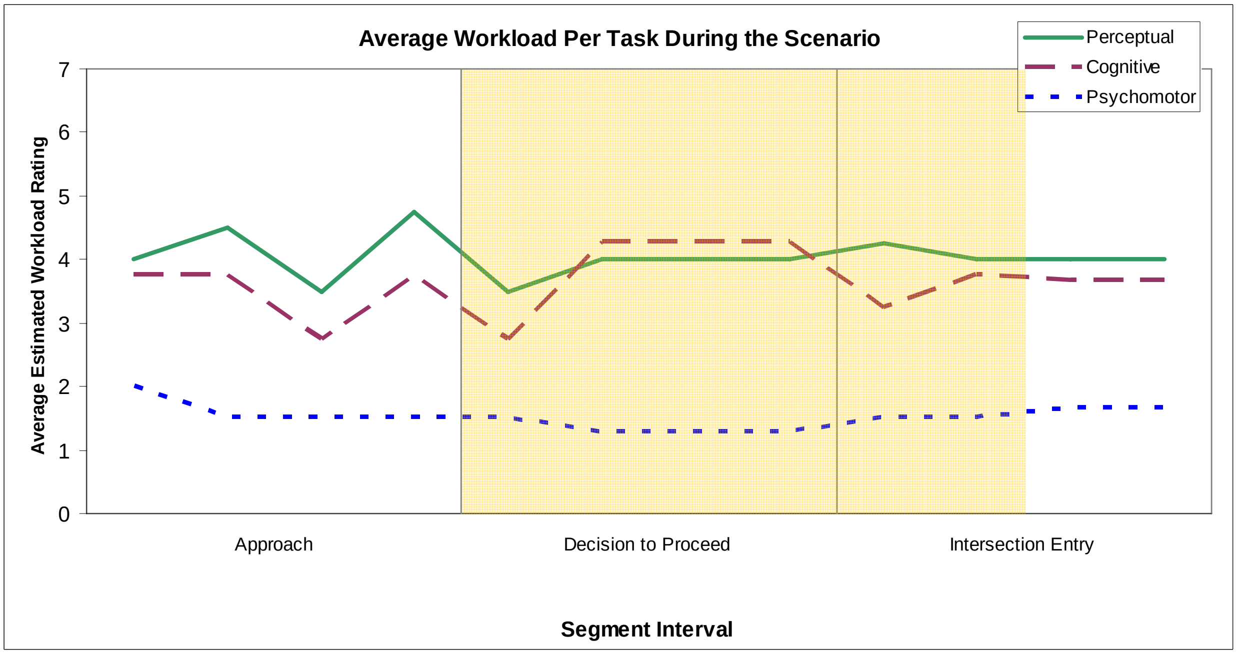
Figure 27 shows the summed workload estimates (separately for each information processing subtask) in each segment interval for the entire scenario. Also, the intervals in which key tasks are forced-paced are shaded in orange. As indicated by figure 27, the workload peaks at higher levels for both the perceptual and cognitive subtasks during the *Decision to Proceed* segment. Perceptual workload also reaches moderate levels in both the *Approach* and *Intersection Entry* segments.

Figure 28, which displays the average workload estimate of all the tasks in play during a particular segment interval, shows that the peak during the *Decision to Proceed* segment in figure 27 arises from several tasks combined rather than fewer, more difficult tasks. This is because the average workload values in this segment are not much greater than in the other segments. Figure 28 does indicate that the peak for cognitive elements occurs in the *Decision to Proceed* segment, but the peaks for the perceptual subtasks mostly occur during the *Approach* segment.




Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph shows the overall level of workload associated with a segment.

**Figure 27. Scenario 3—Straight on Yellow Light total estimated workload ratings for all tasks in each scenario segment.**




Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph generally represents the overall level of difficulty associated with the tasks in a segment.

**Figure 28. Scenario 3—Straight on Yellow Light average estimated workload ratings per task for each scenario segment.**

Information about the combined and average workload ratings, pacing of key tasks, and nature of bottlenecks for each segment are shown in table 40. Only information that represents potential problems is listed; blank cells indicate that no substantive issues occurred for a particular segment or cell. Following the table is a list of key information processing bottlenecks identified in each of the segments.

**Table 40. Scenario 3—Straight on Yellow Light combined and average workload ratings, pacing of key tasks, and the nature of bottlenecks that indicate potential problems for each scenario segment.**

| Segment | Combined Workload | Average Workload | Pacing of Key Tasks | Nature of Bottlenecks |
|---|---|---|---|---|
| *Approach* | Moderate perceptual workload. | High perceptual workload. | | Frequent perceptual tasks involving visual scanning or cognitive tasks involving evaluating multiple factors. |
| *Decision to Proceed* | High perceptual and cognitive workload. | High cognitive workload. | Forced-pacing of all tasks. | Several concurrent tasks with moderate to high perceptual and cognitive workload that must be performed in an extremely limited amount of time. |
| *Intersection Entry* | Moderate perceptual workload. | Moderate to high perceptual workload. | Forced-pacing of key tasks. | A few concurrent tasks with moderate to high levels of perceptual and cognitive workload that must be performed under time pressure. |

Approach nature of bottleneck: Visual demands:

- There is moderate to high combined and average perceptual subtask workload involving some overlapping of visual scanning tasks; however, this situation is offset by the fact that most of the tasks are routine, automatic, and self-paced.

Decision to Proceed nature of bottleneck: High time pressure:

- Combined workload is high for perceptual and cognitive subtasks, and average workload is high for cognitive tasks. The primary difficulty is the limited time to perform key tasks, which is compounded by limitations in available driving options if task completion takes too long.

Intersection Entry nature of bottleneck: Concurrent moderate-to-high workload perceptual tasks with time pressure in the initial stages of the segment:

- Checking for potential hazards from red-light-running cross traffic and left-turning oncoming traffic as the subject vehicle is rapidly approaching the intersection leads to elevated perceptual demands.

## SCENARIO 4—STRAIGHT ON GREEN LIGHT

### Description

This scenario involves the subject vehicle going straight through the intersection on a green light after changing lanes to avoid a vehicle that is stopping to turn in the left lane. Figure 29 shows the scenario diagram and provides additional details regarding the scenario. Briefly described, this scenario involves the driver approaching the intersection and deciding that the light will remain green long enough to get across the intersection. After making the decision to proceed through the intersection, the subject driver observes a left-turning vehicle decelerating in the lane of travel, which requires the driver to change lanes before crossing through the intersection.

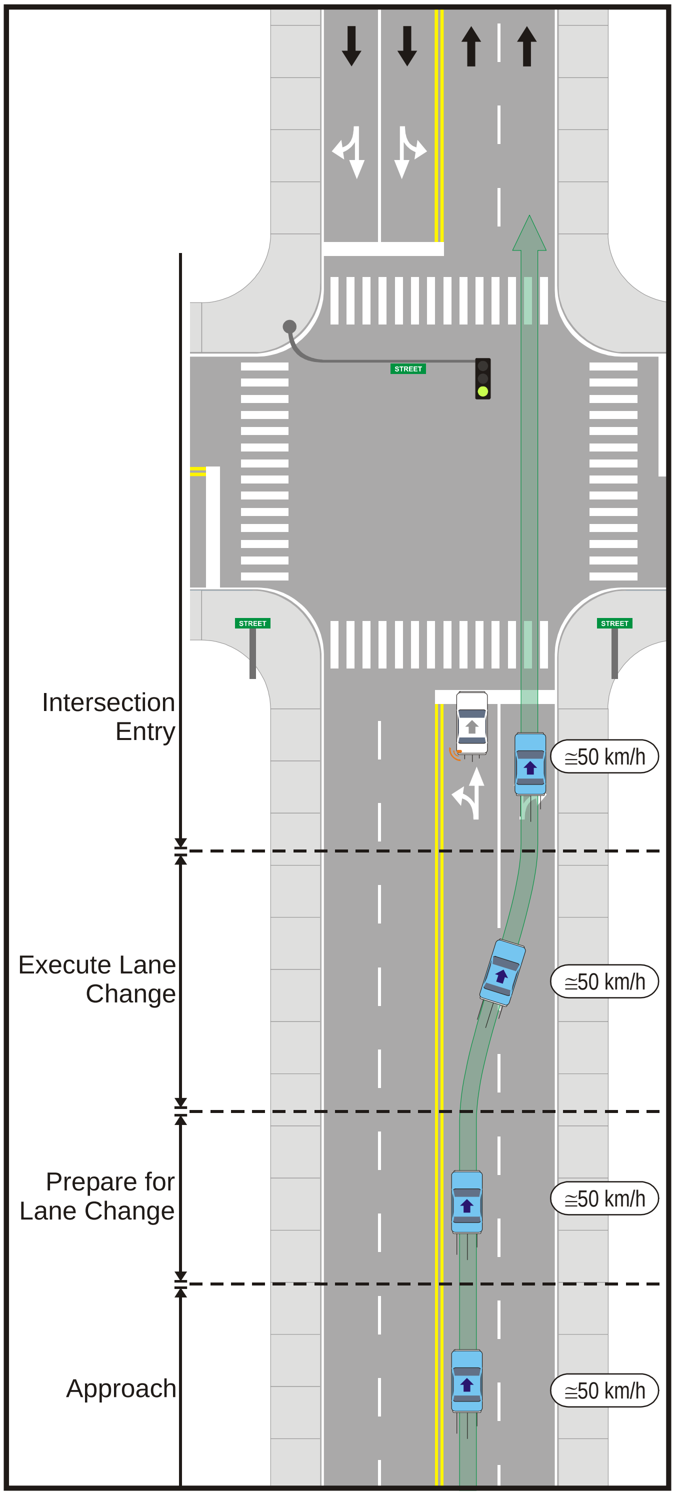
This scenario is divided into four segments *(Approach*, *Prepare for Lane Change*, *Execute Lane Change*, and *Intersection Entry*). The primary reason for parsing this scenario into these segments is that each segment has a different overall driving goal (table 41). Unlike other scenarios, the speed does not vary greatly between segments.

**Table 41. Scenario 4—Straight on Green Light driving objectives and speed characteristics for each scenario segment as a basis for the scenario partitioning.**

| Segment | Driving Objectives | Speed Characteristics |
|---|---|---|
| *Approach* | Gather information about the situation. | Traveling at full speed with some deceleration. |
| *Prepare for Lane Change* | Determine if a lane change is feasible/safe. | Traveling near full speed. |
| *Execute Lane Change* | Maneuver into right lane. | Traveling near full speed with speed adjustments. |
| *Intersection Entry* | Enter and proceed through the intersection. | Traveling near full speed with speed adjustments. |

Because the light remains green throughout this scenario, the dilemma-zone or red-light-running crash issues described in scenario 3 have minimal relevance for identifying potential areas of difficulty. On the other hand, the lane-change element of this scenario provides a potential source of insight into the factors that might lead to crashes in this scenario. Lane change/merge-related crashes accounted for 3.7 percent of all crashes according to 1991 General Estimates System (GES) data, and 22.6 percent of those occurred at intersections or were intersection related.[21] Most of these crashes involved little or no longitudinal gap and a small speed differential between the subject and the POV. Also, crashes were roughly equally distributed among collisions with the front (31.7 percent), middle (26 percent), and rear of the POV (35 percent). The primary causal factors were "looked but did not see" (61.2 percent) and "misjudged" gap/velocity (29.9 percent). This finding suggests that the tasks associated with determining whether it is safe to change lanes in the *Prepare for Lane Change* segment would be key performance bottlenecks in this scenario, especially with the inherent time limitations created by the approaching intersection. Figure 29 lists scenario 4 details and shows the scenario diagram.

**Scenario 4 Diagram**




- Segments are demarked by dotted lines.
- Approximate speed in km/h is indicated on the right.

**Note: Illustration dimensions and vehicle positions are not to scale.**

**Scenario Details**

**Activity**:
Straight on Green Light

**Scenario Segments:**
- Approach
- Lane Change
- Decision to Proceed
- Intersection Entry

**Intersection Configuration**:
Four-lane urban signalized intersection *without* a dedicated left-turn lane.

**Traffic Volume:**
Moderate (driving speeds are at speed limit and other lead/following/adjacent vehicles are present).

**Assumptions/Complicating Factors**:
- There is no dedicated left-turn lane or turn signal.
- The signal will remain green until the subject vehicle crosses the intersection, and the visual cues (e.g., pedestrian signal) are consistent with this situation.
- A left-turning vehicle is stopped ahead in the subject vehicle's lane.
- The decision to go through the intersection can be made far enough away from the intersection that there is enough room to execute the lane change.
- There is traffic in the right lane that is in front and behind the subject vehicle traveling at speed, but otherwise there is a sufficient gap to change lanes.
- The subject is being followed by another vehicle in the originating lane.

**Figure 29. Scenario 4—Straight on Green Light diagram, details, and assumptions.**

Several assumptions were made about the situational aspects of the scenario. The justifications for these are summarized in figure 29 and more fully described in table 42.

**Table 42. Scenario 4—Straight on Green Light assumptions and corresponding justifications.**

| Assumption | Justification |
|---|---|
| The signal will remain green until the subject vehicle crosses the intersection and the visual cues (e.g., pedestrian signal) are consistent with this green light. | This situation provides some motivation for changing lanes, rather than stopping and waiting for a new cycle. |
| A vehicle that is far ahead signals for a left turn during the Approach Segment. | This situation necessitates a lane change, but because the vehicle is far ahead, it will not interfere with the subject vehicle's ability to change lanes. |
| The decision to go through the intersection can be made far enough away from the intersection to ensure enough room to execute the lane change. | This situation makes the lane change possible. |
| There is traffic in the right lane that is in front and behind the subject vehicle traveling at speed, but otherwise there is a sufficient gap to change lanes. | This situation makes the lane change more difficult and introduces the risk of a traffic conflict while still making it possible to change lanes. |

### Scenario 4 Timeline

An approximate timeline showing the key temporal milestones for scenario 4 was calculated based on vehicle kinematics (figure 30). These milestones were used to make judgments about the pacing of tasks within segments in addition to providing a basis for the overall sequencing of certain tasks.

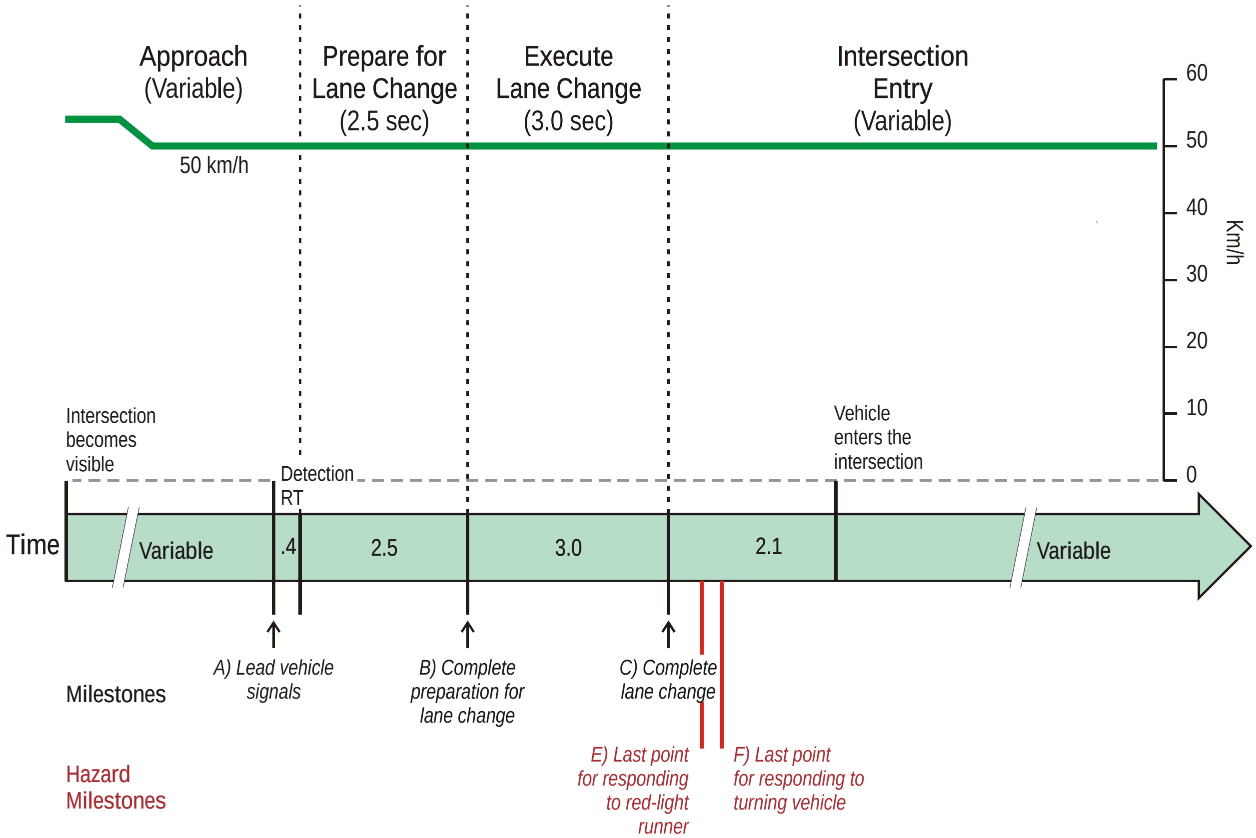



**Figure 30. Scenario 4—Straight on Green Light timeline of key segment phases duration and event/task milestones.**

One aspect of the timing that deserves discussion is that the times provided for planning and executing lane changes (2.5 and 3.0 sec, respectively), are shorter than what is typically observed in other research (see also appendix A). Shorter times were used to reflect the fact that the lane changes must be completed quickly because the driver is approaching the intersection.

### Task Analysis Table

The results of the task analysis organized by scenario segment are shown in the task analysis table (table 43). The task analysis results are duplicated for individual segments in the segment analyses tables in the next sections, which more fully discuss the organization and content of the tasks and information processing subtasks.

**Table 43. Scenario 4—Straight on Green Light task analysis table.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **4.1. Approach** | | | |
| 4.1.1 Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 4.1.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 4.1.4 Decelerate. | Visually assess distance to intersection. | Determine when vehicle is close enough to intersection to begin deceleration. | Coast (foot off accelerator) and/or gentle braking. |
| 4.1.5 Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location, etc. | Determine if any nonroutine actions are required. | Head and eye movements for scanning. |
| 4.1.6 Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 4.1.7 Determine if the light is about to change. | Visually observe the scene for key cues (check pedestrian signal). | Identify that walk pedestrian signal means that the light will stay green. | Head and eye movements for scanning. |
| 4.1.8 Observe that lead vehicle is signaling a left turn. | Visually observe lead vehicle left-turn signal. | Determine that lead vehicle intends to turn left. | Head and eye movements for viewing lead vehicle. |
| **4.2. Prepare for Lane Change** | | | |
| 4.2.1 Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 4.2.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 4.2.4 Decide whether lane change is legally permissible (e.g., lane markings are not solid). | Scan for signs prohibiting lane change. Visually observe pavement markings. | Make yes/no decision regarding legality based on observed information. | Head and eye movements for looking for indicators. |
| 4.2.5 Determine whether there is a sufficient gap in right lane. | Visually observe leading or adjacent traffic in right lane. | Determine if there is sufficient space in the right lane or if deceleration is required. | Head and eye movements for viewing right lane. |
| 4.2.6 Check rearview mirror for rear-approaching traffic in right lane. | Observe presence and relative speed of rear-approaching traffic. | Determine if there will be a potential conflict with rear-approaching traffic. | Head and eye movements to observe rearview mirror. |
| 4.2.7 Check blind spot for rear-approaching traffic in right lane. | Visually observe right lane over shoulder. | Identify if any vehicles are present. | Head and eye movements to perform shoulder check. |

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **4.3. Execute Lane Change** | | | |
| 4.3.1 Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 4.3.3 Activate turn signal. | Locate the control (automatic behavior). | Identify which direction to activate the control (automatic behavior). | Activate turn signal control. |
| 4.3.4 Adjust vehicle speed to avoid conflicts with right-lane lead vehicle traveling at constant speed. | Visually assess distance and relative speed of lead vehicle in right lane. | Determine if distance and relative speed are safe. | Decelerate if necessary.<br>Head and eye movements to view vehicle. |
| 4.3.5 Adjust vehicle speed to avoid conflicts with right-lane following vehicle traveling at constant speed. | Visually assess distance and relative speed of following vehicle in right lane. | Determine if distance and relative speed are safe. | Accelerate if necessary<br>Head and eye movements to view vehicle. |
| 4.3.6 Change lane. | Visually observe vehicle lateral position. | Identify when vehicle is completely in new lane. | Steer into new lane and adjust vehicle position. |
| **4.4. Intersection Entry** | | | |
| 4.4.1 Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 4.4.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 4.4.3 Maintain safe distance from lead vehicle traveling at constant speed. | Visually assess distance and relative speed of leading vehicle. | Determine if lead-vehicle trajectory is safe. | Reduce speed if necessary.<br>Head and eye movements to view vehicle. |
| 4.4.4 Check that there will be no conflict with following vehicle. | Visually assess distance and relative speed of following vehicle. | Determine if following-vehicle closing trajectory is safe. | Head and eye movements to observe rearview mirror. |
| 4.4.5 Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | Determine if crossing vehicles are stopped or will stop in time. | Head and eye movements for observing cross traffic. |
| 4.4.6 Check for oncoming vehicle trying to turn left across path. | Look for signs of vehicle turning (turn signal, stopped in intersection). | Decide if oncoming vehicle is turning. | Head and eye movements to view oncoming vehicle. |

## Segment Analysis

### *Scenario 4, Segment 1, Approach*

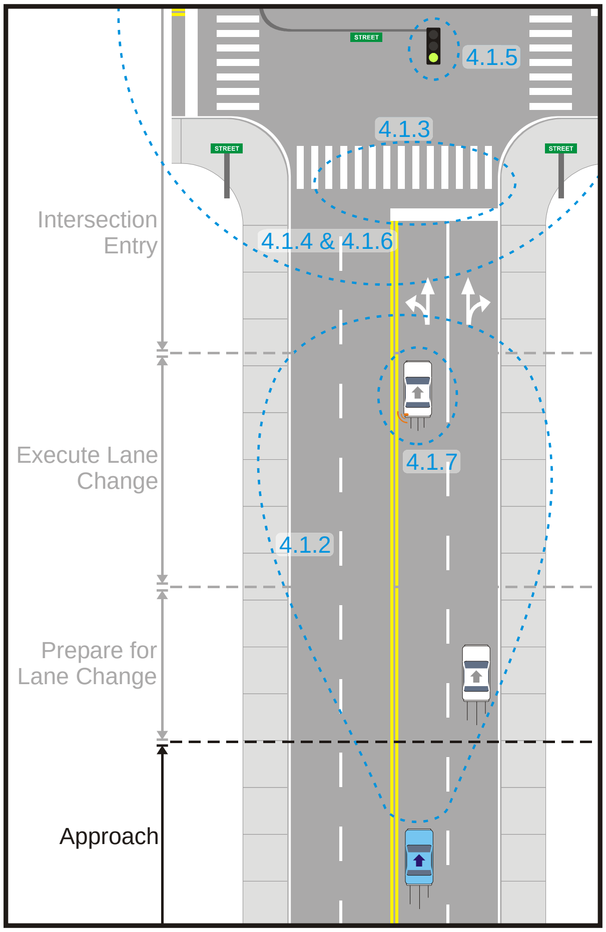
The *Approach* segment involves the subject vehicle traveling at full speed until the subject vehicle driver observes that the lead vehicle is signaling to turn (which prompts the decision to consider changing lanes—next segment). The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 44. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 31 and table 45.

**Table 44. Scenario 4—Straight on Green Light *Approach* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 4.1.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 4.1.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 4.1.3 Decelerate. | Visually assess distance to intersection. | **4** | Determine when vehicle is close enough to intersection to begin deceleration. | **6** | Coast (foot off accelerator) and/or gentle braking. | **3** |
| 4.1.4 Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location, etc. | **6** | Determine if any nonroutine actions are required. | **6** | Head and eye movements for scanning. | **1** |
| 4.1.5 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 4.1.6 Determine if the light is about to change. | Visually observe the scene for key cues (check pedestrian signal). | **3** | Identify that walk pedestrian signal means that the light will stay green. | **2** | Head and eye movements for scanning. | **1** |
| 4.1.7 Observe that lead vehicle is signaling a left turn. | Visually observe lead vehicle left-turn signal. | **1** | Determine that lead vehicle intends to turn left. | **1** | Head and eye movements for viewing lead vehicle. | **1** |

Some assumptions about the task analysis and workload estimation warrant discussion. One is the assumption that the pedestrian signal is visible to the driver during the approach, and it displays the walk signal indicating that the light will remain green in the near future. Observing the pedestrian signal was mentioned as a common strategy in intersection approaches by drivers of all ages in the focus group component of this project.[22] This assumption consequently simplifies task 4.1.7 (*determine if the light is about to change*) and provides some variety from the other scenarios. It is also the most likely situation because the light is assumed to be early in the green phase. Another assumption is that the lead vehicle does not start signaling the turn until after the subject vehicle has completed task 4.1.6, which occurs because this event is the boundary between this segment and the next.

**Scenario 4, Segment 1 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 31. Scenario 4—Straight on Green Light *Approach* segment diagram.**

**Table 45. Relative timing and duration of segment tasks and summary of key findings for the *Approach* segment of Scenario 4—Straight on Green Light.**

| .Task | Approximate Task Duration within Segment Timeframe (Time: *Start* → *End*) |
|---|---|
| **4.1 Approach** | |
| 4.1.1 Maintain safe lane position. | F (start to end) |
| 4.1.2 Check surround for unsafe situations. | S (start to end) |
| 4.1.3 Decelerate. | S (near start) |
| 4.1.4 Identify intersection characteristics. | S |
| 4.1.5 Observe status of light. | S (middle) |
| 4.1.6 Determine if the light is about to change. | S |
| 4.1.7 Observe that lead vehicle is signaling a left turn. | F (at end) |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Demanding perceptual tasks in 4.1.2 and 4.1.4.
- Cognitive tasks involving evaluation or judgment of several factors in 4.1.3 and 4.1.4.

***Mitigating factors:***

- Most of the difficult tasks are self-paced.
- Many tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 4.1.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Task 4.1.7 (*observe that lead vehicle is signaling a left turn*) is forced-paced because the driver has a limited amount of time to notice the turning vehicle and decide to change lanes because the intersection is rapidly approaching.

Regarding the task ordering, tasks 4.1.3 through 4.1.6 are sequential and can essentially be performed in any order. The ordering chosen in this segment followed a logical sequence and was consistent with the ordering of similar tasks in other scenario *Approach* segments. Task 4.1.7 was simply assumed to occur last because it was the transition point to the next segment.

### *Scenario 4, Segment 2, Prepare for Lane Change*

The *Prepare for Lane Change* segment spans the time from when the subject driver observes the lead vehicle signaling to turn to when the driver decides that it is legal and safe to make a lane change. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 46. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 32 and table 47.

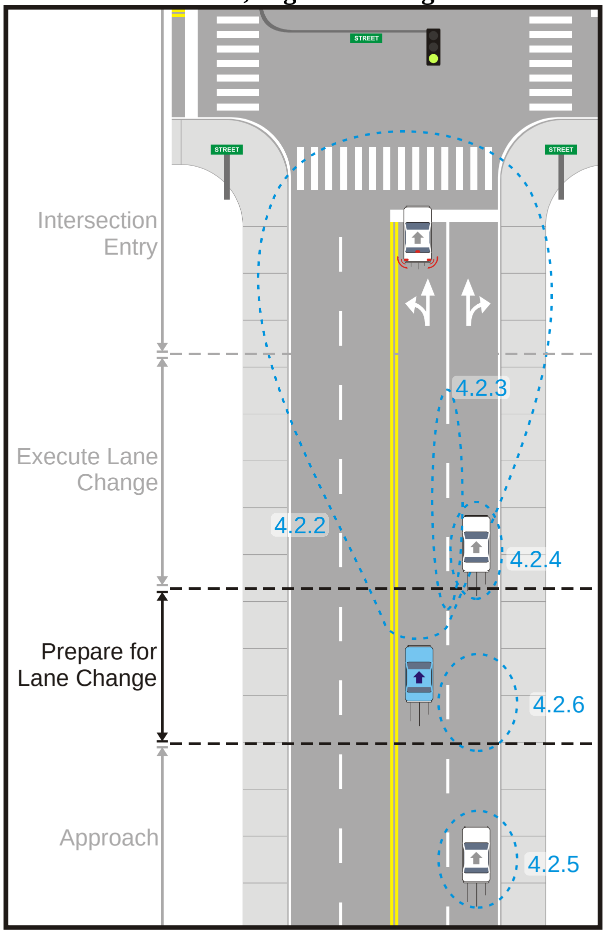
**Table 46. Scenario 4—Straight on Green Light *Prepare for Lane Change* segment of tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 4.2.1 Maintain safe lane position. | Visually observe roadway ahead. | 1 | Verify correct lane position. | 1 | Make necessary adjustments to steering. | 1 |
| 4.2.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | 7 | Determine whether perceptual input indicates if current situation is safe/unsafe. | 4 | Head and eye movements for scanning. | 1 |
| 4.2.3 Decide whether lane change is legally permissible (e.g., lane markings are not solid). | Scan for signs prohibiting lane change. Visually observe pavement markings. | 7 | Interpret information regarding legality based on observed information. | 5 | Head and eye movements for looking for indicators. | 1 |
| 4.2.4 Determine whether there is a sufficient gap in right lane. | Visually observe leading or adjacent traffic in right lane. | 4 | Determine if there is sufficient space in the right lane or if deceleration is required. | 4 | Head and eye movements for viewing right lane. | 1 |
| 4.2.5 Check rearview mirror for rear-approaching traffic. | Identify presence and relative speed of rear-approaching traffic. | 4 | Determine if there will be a potential conflict with rear-approaching traffic.* | 5 | Head and eye movements to observe rearview mirror. | 1 |
| 4.2.6 Check blind spot for rear-approaching traffic in right lane. | Visually observe right lane over shoulder. | 1 | Identify if any vehicles are present. | 2 | Head and eye movements to perform shoulder check. | 1 |

* Difficulty is increased by a value of 1 because of degraded information.

Several points about the task analysis and workload estimation warrant discussion. The first is that task 4.2.4 (*determine whether there is a sufficient gap in right lane*) was added to this segment because it is first necessary to determine whether there is room to change lanes and if a speed adjustment is necessary before checking for rear-approaching traffic.[24] It is also noteworthy that no separate task is defined for the actual decision about whether to change lanes. This decision process is the culmination of tasks 4.2.3 through 4.2.6, and the assumption is that the decision is an implicit result of resolving these tasks. Finally, the workload value of the task 4.2.5 (*check rearview mirror for rear-approaching traffic*) cognitive subtask was incremented because the driver must deal with degraded information from the rearview mirror.

**Scenario 4, Segment 2 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 32. Scenario 4—Straight on Green Light *Prepare for Lane Change* segment diagram.**

**Table 47. Scenario 4—Straight on Green Light *Prepare for Lane Change* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **4.2 Prepare for Lane Change** | **Time** *Start* → *End* |
| 4.2.1 Maintain safe lane position. | F |
| 4.2.2 Check surround for unsafe situations. | S |
| 4.2.3 Decide whether lane change is legally permissible. | F |
| 4.2.4 Determine whether there is a sufficient gap in right lane. | F |
| 4.2.5 Check rearview mirror for rear-approach traffic. | F |
| 4.2.6 Check blind-spot for rear approaching traffic in right lane. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Perceptual tasks involving scanning in 4.2.2, & 4.2.3.
- Cognitive tasks involving interpretation of information in 4.2.3 and evaluation a single factor under difficult conditions in 4.2.5.
- Tasks 4.2.3 through 4.2.6 are forced-paced and must be completed in a relatively short period of time.
- Visual information sources are distributed throughout the scene.

***Mitigating factors:***

- None.

*Task Pacing and Timing*—Task 4.2.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Tasks 4.2.3 through 4.2.6 are forced-paced because they must be completed before initiating the lane change, which is itself constrained by the approaching intersection.

In the task ordering, tasks 4.2.3 through 4.2.6 are shown as overlapping sequential tasks that follow the sequence described in the McKnight and Adams task analysis.(9) The reason for presenting them in this way is that these tasks all involve visual information acquisition (which can only be done in sequence) that requires precise yet rapid deployment of visual gaze and attention to distributed locations throughout the visual scene. Consequently, there is likely to be some interference between sequential tasks; however, because more time is available than in other time-limited segments with task interference (e.g., *Decision to Proceed* in scenario 3), the overlap was limited to adjacent tasks, rather than making them all simultaneous.

### *Scenario 4, Segment 3, Execute Lane Change*

The *Execute Lane Change* segment spans the time from when the subject vehicle initiates the lane change until the driver is established in the new lane. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 48. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 33 and table 49.

**Table 48. Scenario 4—Straight on Green Light *Execute Lane Change* segment tasks and information processing subtasks.**

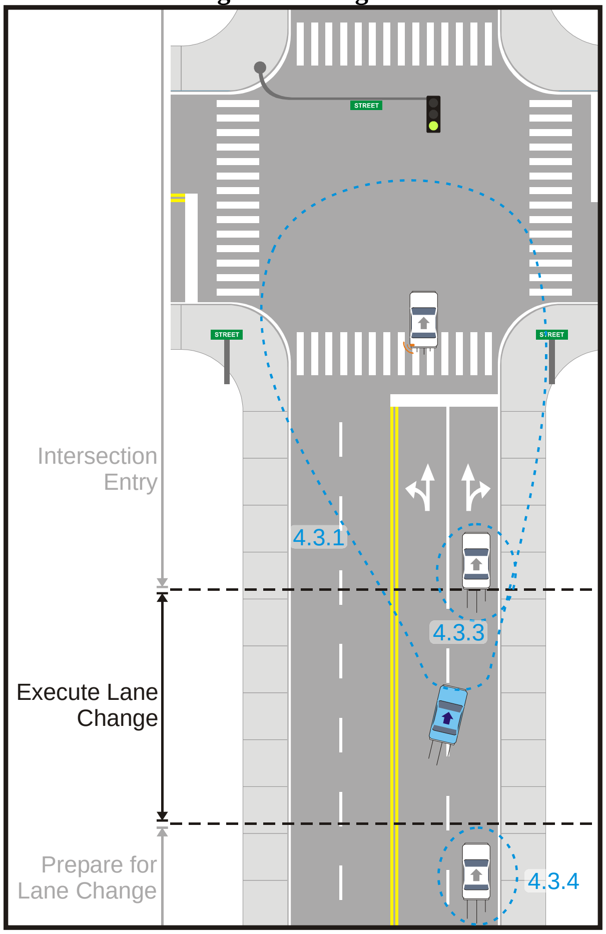
| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 4.3.1 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 4.3.2 Activate turn signal. | Locate the control (automatic behavior). | **1** | Identify which direction to activate the control (automatic behavior). | **1** | Activate turn signal control. | **1** |
| 4.3.3 Adjust vehicle speed to avoid conflicts with right-lane lead vehicle traveling at constant speed. | Visually assess distance and relative speed of lead vehicle in right lane. | **4** | Determine if distance and relative speed are safe. | **6** | Decelerate if necessary. Head and eye movements to view vehicle. | **3** |
| 4.3.4 Adjust vehicle speed to avoid conflicts with right-lane following vehicle traveling at constant speed. | Visually assess distance and relative speed of following vehicle in right lane. | **4** | Determine if distance and relative speed are safe.* | **7** | Accelerate if necessary. Head and eye movements to view vehicle. | **3** |
| 4.3.5 Change lane. | Visually observe vehicle lateral position. | **1** | Identify when vehicle is completely in new lane. | **2** | Steer into new lane and adjust vehicle position. | **3** |

* Difficulty in this subtask is increased by a value of 1 because of degraded information.

Several aspects of the task analysis and workload estimation warrant discussion. The first is that task 4.3.3 (*activate turn signal*) was included in this segment because this task should be performed after determining that it is legal and safe to change lanes. Although this task could have been included in the previous segment, it was included here largely because research indicates that in practice, many drivers do not activate the turn signal until the lane change is underway.[(25)] Also, the turn signal activation workload demands were assigned the minimum value of 1 because this is a learned automatic activity. Another point is that the *maintain safe lane position* task was not included in this segment because the subject vehicle is changing lanes during this segment.

One assumption in this segment is that tasks 4.3.5 and 4.3.6 (*avoiding conflicts with lead and following vehicles in the right lane*) do not conflict (e.g., that a speed change required to avoid the lead vehicle will not cause a conflict with the following vehicle) because it is likely that the driver would have decided earlier that there was an insufficient gap to change lanes. Finally, the estimated workload value for the task 4.3.5 cognitive subtask was incremented by a value of 1, because determining whether the relative speed and distance of the following vehicle are safe is more difficult to do using the degraded indirect visual information from the rearview mirror.

**Segment 3 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 33. Scenario 4—Straight on Green Light *Execute Lane Change* segment of scenario diagram.**

**Table 49. Scenario 4—Straight on Green Light *Execute Lane Change* segment of relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **4.3 Execute Lane Change** | **Time** *Start* → *End* |
| 4.3.1 Check surround for unsafe situations. | S |
| 4.3.2 Activate turn signal. | F |
| 4.3.3 Adjust vehicle speed to avoid conflicts with right-lane lead vehicle. | F |
| 4.3.4 Adjust vehicle speed to avoid conflicts with right-lane following vehicle. | F |
| 4.3.5 Change lane. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Demanding cognitive tasks involving evaluation of multiple factors in 4.3.3 & 4.3.4.
- Tasks 4.3.2 to 4.3.5 are forced-paced and must be completed in a relatively short period of time.

***Mitigating Factors:***

- Most of the tasks are routine.

*Task Pacing and Timing*—Tasks 4.3.2 through 4.3.5 are forced-paced because they must be completed before the subject vehicle gets too close to the intersection.

In the task ordering, task 4.3.2 (*activate the turn signal*) initiates the segment, whereas tasks 4.3.3 and 4.3.4 are ongoing both before and during the actual lane-change maneuver (task 4.3.5).

### *Scenario 4, Segment 4, Intersection Entry*

The *Intersection Entry* segment spans the time from when the driver has completed the lane change and is established in the new lane to when the subject vehicle crosses to the other side of the intersection. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 50. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 34 and table 51.

**Table 50. Scenario 4—Straight on Green Light *Intersection Entry* segment tasks and information processing subtasks.**

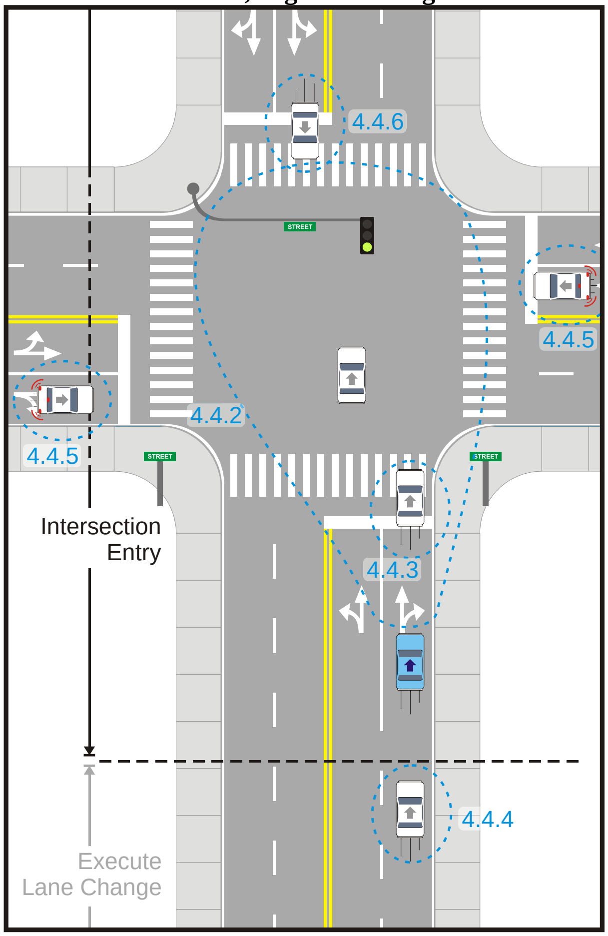
| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 4.4.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 4.4.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 4.4.3 Maintain safe distance from lead vehicle traveling at constant speed. | Visually assess distance and relative speed of leading vehicle. | **4** | Determine if distance and relative speed are safe. | **4** | Reduce speed if necessary. Head and eye movements to view vehicle. | **3** |
| 4.4.4 Check that there will be no conflict with following vehicle. | Visually assess distance and relative speed of following vehicle. | **4** | Determine if following-vehicle closing trajectory is safe.* | **5** | Head and eye movements to observe rearview mirror. | **3** |
| 4.4.5 Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | **5** | Determine if crossing vehicles are stopped or will stop in time. | **4** | Head and eye movements for observing cross traffic. | **1** |
| 4.4.6 Check for oncoming vehicle trying to turn left across path. | Look for signs of vehicle turning (turn signal, stopped in intersection). | **4** | Decide if oncoming vehicle is turning. | **6** | Head and eye movements to view oncoming vehicle. | **1** |

* Difficulty in this subtask is increased by a value of 1 because of degraded information.

Task 4.4.4 (*check that there will be no conflict with following vehicle*) is included in this segment as a quick doublecheck for potential conflict with the following vehicle. This action is a check for the possibility that the subject vehicle has misjudged the available space, or that the following vehicle was distracted and adopted an unsafe trajectory. In the McKnight and Adams task analysis,[9] the corresponding task is designed to check to see if the following vehicle is trying to overtake or pass. This situation is unlikely to apply this close to the intersection; thus, the purpose of task 4.4.4 was just to doublecheck for conflict.

Also, tasks 4.4.3 (*maintain safe distance from lead vehicle traveling at constant speed*) and 4.4.4 cognitive subtasks were treated as involving the evaluation of a single dimension (workload estimate = 4), rather than as the evaluation of multiple dimensions (workload estimate = 6) based on relative speed and distance. The reason for this type of treatment is that evidence suggests that drivers may evaluate time-to-arrival as a single integrated variable (*tau*) rather than as separate speed and distance components.[11] In addition, the estimated workload value for the task 4.4.4 cognitive subtask was incremented by a value of 1, because determining the trajectory of the following vehicle is more difficult to do using the degraded indirect visual information from the rearview mirror.

**Scenario 4, Segment 4 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 34. Scenario 4—Straight on Green Light *Intersection Entry* segment diagram.**

**Table 51. Scenario 4—Straight on Green Light *Intersection Entry* segment of relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **4.4 Intersection Entry** | **Time** *Start* → *End* |
| 4.4.1 Maintain safe lane position. | F |
| 4.4.2 Check surround for unsafe situations. | S |
| 4.4.3 Maintain safe distance from lead vehicle traveling at constant speed. | S |
| 4.4.4 Check that there will be no conflict with following vehicle. | S |
| 4.4.5 Check for red-light running cross traffic. | F |
| 4.4.6 Check for oncoming vehicle trying to turn left across path. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and successive visual scanning (4.4.2) and visual monitoring/localization tasks (4.4.5 & 4.4.6) that must be completed quickly.
- Some of the critical safety-related tasks are forced-paced.

***Mitigating Factors:***

- Several of the tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 4.4.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Tasks 4.4.5 (*check for red-light-running traffic*) and 4.4.6 (*check for oncoming turning vehicles*) are forced-paced because they have to be completed as the subject vehicle is rapidly approaching the intersection.

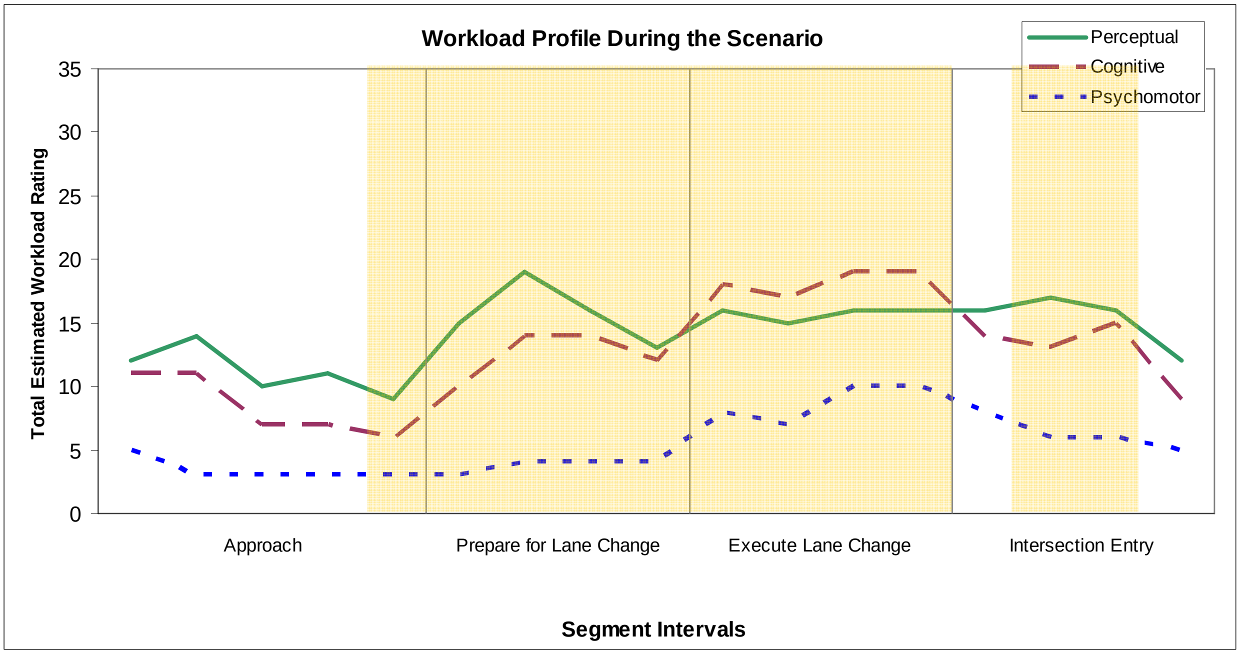
In the task ordering, task 4.4.3 (*maintain safe distance from following vehicle*) occurs first because this task should be performed soon after arriving in the new lane because its purpose is to doublecheck for potential conflicts. Also, tasks 4.4.5 and 4.4.6 are ordered based on which one is encountered first, and the other tasks are concurrent.

**Scenario-Wide Analysis**

To help identify potential information processing bottlenecks in this scenario, workload estimates from all segments were combined into a single scenario-wide workload profile that provides a general indication of where the areas of high workload demands are likely to be.

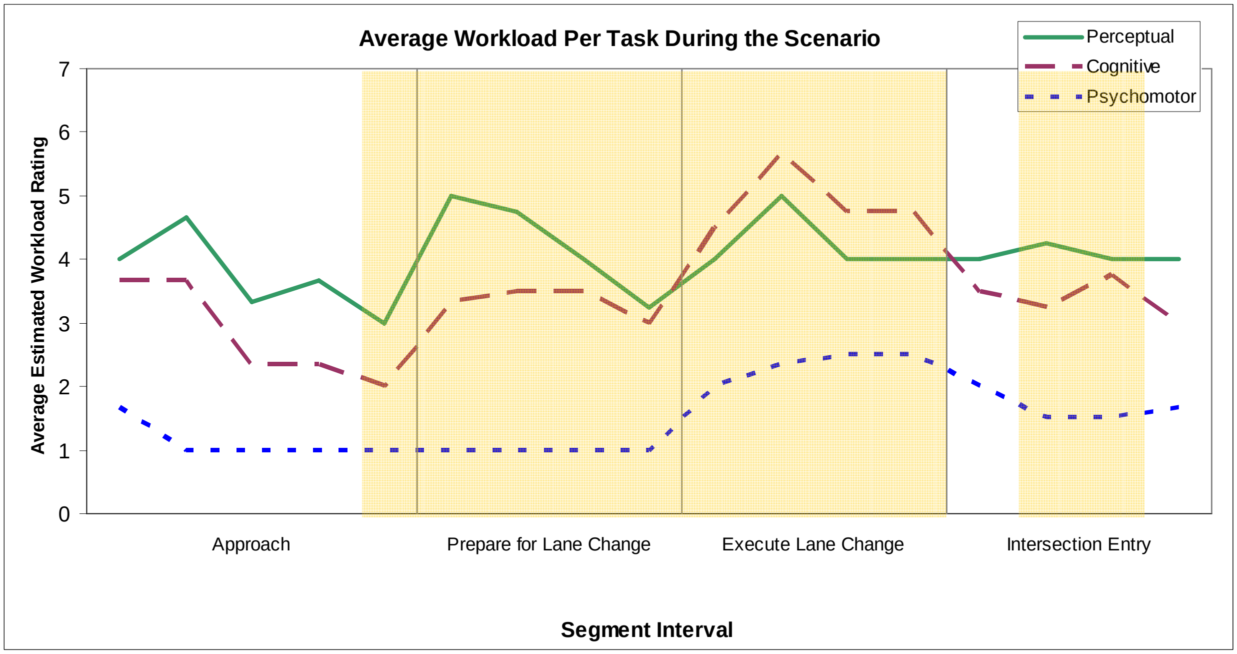
Figure 35 shows the summed workload estimates (separately for each information processing subtask) in each segment interval for the entire scenario. Also, the intervals in which key tasks are forced-paced are shaded in orange. As indicated by figure 35, the workload levels peak at moderate to high levels for the perceptual elements during the *Prepare for Lane Change* segment and remain at moderate levels beyond that. The cognitive elements peak at moderate to high levels at the *Execute Lane Change* segment and remain at moderate levels during the *Prepare for Lane Change* and *Intersection Entry* segments.

Figure 36, which displays the average workload estimate of all the tasks in play during a particular segment interval, shows that there is a peak at high levels for cognitive elements during the *Execute Lane Change* segment. This high average workload level associated with the underlying tasks is likely responsible for the corresponding peak in the combined workload profile for cognitive tasks (figure 35). Similarly, average workload levels are relatively high for the perceptual elements in all segments, but peak in the *Prepare for Lane Change* segment, which suggests that the corresponding peak in the combined workload profile (figure 35) arises from high workload levels of the tasks, rather than solely from a high number of overlapping tasks.




Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph shows the overall level of workload associated with a segment.

**Figure 35. Scenario 4—Straight on Green Light total estimated workload ratings for all tasks in each scenario segment.**




Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph generally represents the overall level of difficulty associated with the tasks in a segment.

**Figure 36. Scenario 4—Straight on Green Light average estimated workload ratings per task for each scenario segment.**

### *Information Processing Bottlenecks*

Information about the combined and average workload ratings, pacing of key tasks, and nature of bottlenecks for each segment is shown in table 52. Only information that represents potential problems is listed; blank cells indicate that no substantive issues occurred for a particular segment or cell. Following the table is a list of key information processing bottlenecks identified in each of the segments.

**Table 52. Combined and average workload ratings, pacing of key tasks, and nature of bottlenecks that indicate potential problems for each scenario segment.**

| Segment | Combined Workload | Average Workload | Pacing of Key Tasks | Nature of Bottlenecks |
|---|---|---|---|---|
| *Approach* | | High perceptual workload. | Some forced-paced tasks. | Perceptual tasks involving scanning or reading and cognitive tasks involving judging multiple factors. |
| *Prepare for Lane Change* | Moderate perceptual workload. | High perceptual workload. | Forced-pacing of key tasks. | Rapid sequence of perceptual and cognitive tasks with moderate to high workload that involve distributed information and high time pressure. |
| *Execute Lane Change* | Moderate cognitive workload. | High perceptual and cognitive workload. | Forced-pacing of key tasks. | Concurrent and continuous perceptual and cognitive tasks with moderate to high workload conducted under time pressure. |
| *Intersection Entry* | | High perceptual workload. | Forced-pacing of some key tasks. | Perceptual and cognitive tasks with moderate to high workload that involve distributed information with some time pressure. |

*Prepare for Lane Change* nature of bottleneck: High time pressure:

- Several tasks involving moderate to high perceptual and cognitive workload focused on obtaining information from the environment are needed to decide whether or not a lane change can be made. These tasks must be performed in rapid succession under high time pressure because the time available to make the decision is limited by the approaching intersection.

*Execute Lane Change* nature of bottleneck*:* High time pressure:

- There are concurrent and ongoing perceptual and cognitive tasks with moderate to high workload conducted under time pressure because the subject vehicle must safely get into the new lane with sufficient time to perform the *Intersection Entry* tasks. These effects are mitigated somewhat because most of these tasks are routine, automatic activities.

*Intersection Entry* nature of bottleneck*:* Distributed information:

- There are perceptual and cognitive tasks with moderate to high workload that involve information distributed throughout the visual scene with time pressure for some of the safety-related tasks. These effects are partially diminished because some of these tasks are routine, automatic activities.

## SCENARIO 5—RIGHT TURN ON GREEN LIGHT

### Description

This scenario involves the subject vehicle making a right turn on a green light. Figure 37 shows the scenario diagram and provides additional details regarding the scenario. Briefly described, this scenario involves the subject driver identifying the intersection as the turn location, then decelerating to turn speed. Following this action, the subject driver determines that it is safe to go, advances into the intersection, and executes the turn while at the same time watching out for conflicts with an oncoming vehicle making a left turn into the adjacent lane.

This scenario was divided into four segments (*Approach*, *Deceleration*, *Intersection Entry*, and *Execute Turn*). The primary bases for parsing the scenario into these particular segments were that each segment had a different overall driving goal and each had different speed characteristics (table 53).

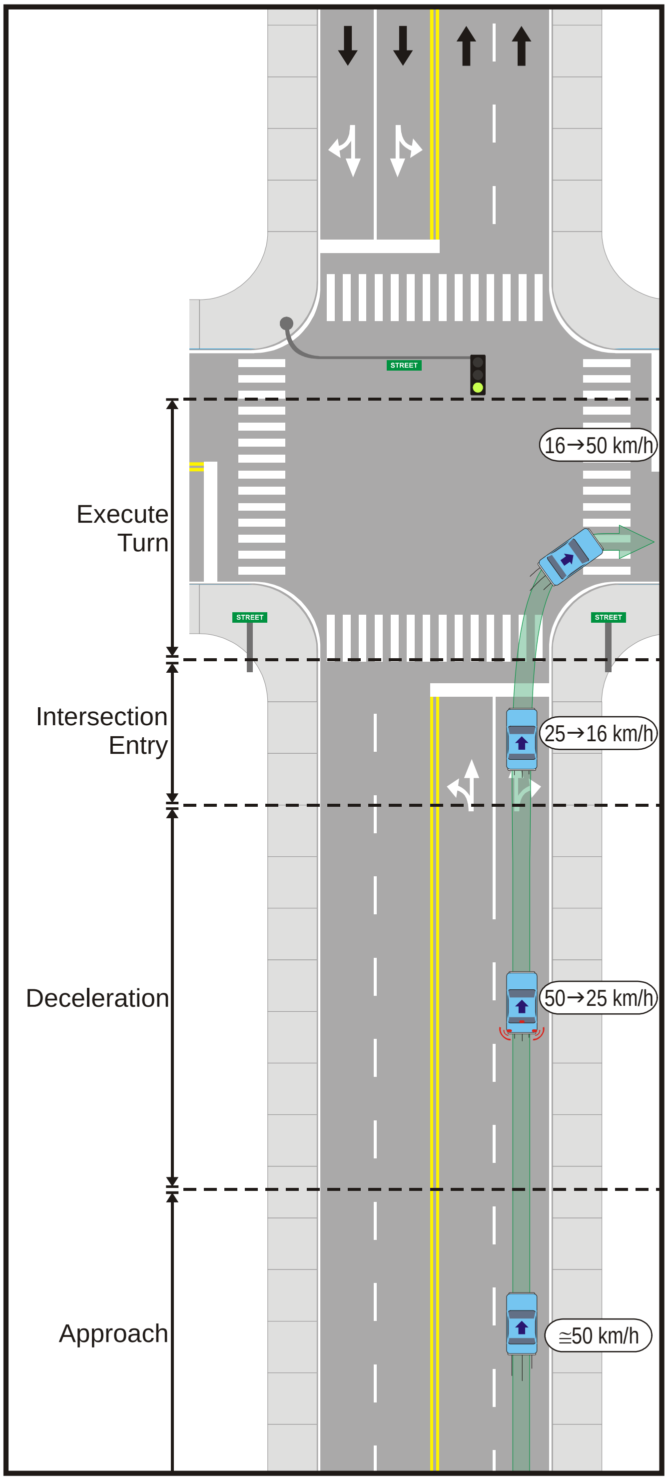
**Table 53. Scenario 5—Right Turn on Green Light driving objectives and speed characteristics for each scenario segment used as a basis for the scenario partitioning.**

| Segment | Driving Objectives | Speed Characteristics |
|---|---|---|
| *Approach* | Identify upcoming intersection as the location of the turn. | Traveling at full speed. |
| *Deceleration* | Arrive at the intersection at turning speed. | Controlled deceleration. |
| *Intersection Entry* | Get into position to turn. Decide that it is safe to turn. | Traveling at slow speed. |
| *Execute turn* | Make the turn. | Turning and accelerating up to speed. |

The crash data related to this scenario indicate some characteristics that are relevant to the task analysis and configuration of this scenario. According to 1998 GES data, 5.7 percent of crossing path crashes involved right turns, 20 percent of which occurred at signalized intersections.(26) The most common violations charged in right-turn crashes at signalized intersections were “failure to yield right of way” (19.2 percent ), followed by “other violation” (15.9 percent), and “running a traffic signal” (4.1 percent).(26) Another notable finding from these same researchers(26) [Correct reference?]is that right-turning drivers had higher rates of reported involvement of driver distraction in crashes at signalized intersections (5.5 percent) compared to drivers making left turns [3.1 percent left turn across path–opposite direction (LTAP/OD) conflict; 1.5 percent left turn across path–lateral direction (LTAP/LD) conflict] or going straight (2.7 percent straight crossing paths) . In addition, the same report indicates that vision obstruction was not reported as a factor in any right-turn crashes at signalized intersections in the 1998 GES data sample used. This finding suggests that the cognitive subtasks in the *Intersection Entry* segment are likely to be primary sources of difficulty.

Figure 37 shows the scenario 5 diagram, and table 54 lists scenario 5 details.

**Scenario 5 Diagram**




- Segments are demarked by dotted lines.
- Approximate speed in km/h is indicated on the right.

**Note: Illustration dimensions and vehicle positions are not to scale.**

**Scenario Details**

**Activity**:
Left Turn on a Green Light

**Scenario Segments:**
- Approach
- Deceleration
- Intersection entry
- Execute turn

**Intersection Configuration**:
Four-lane urban signalized intersection *without* a dedicated left-turn lane or a left-turn signal.

**Traffic Volume:**
Moderate (driving speeds are at speed limit and other lead/following/adjacent vehicles are present).

**Assumptions/Complicating Factors**:
- The subject vehicle is not following any vehicles but is followed by another vehicle.
- The turn intersection is unfamiliar to the subject driver.
- No lane change is required to get into the turning lane.
- An oncoming vehicle is making a left turn into the inside lane (adjacent to the subject vehicle destination lane).

**Figure 37. Scenario 5—Right Turn on Green Light diagram, details, and assumptions.**

Several assumptions were made regarding the situational aspects of the scenario. The justifications for these are summarized in figure 37 and more fully described in table 54.

**Table 54. Scenario 5—Right Turn on Green Light assumptions and corresponding justifications.**

| Assumption | Justification |
|---|---|
| The subject vehicle is not following any vehicles but is followed by another vehicle. | Including the following traffic makes the deceleration-related tasks more demanding. The lead vehicle was excluded because it is irrelevant in this scenario because it would pull far ahead once the subject began decelerating for the turn. |
| The turn intersection is unfamiliar to the subject driver. | Identifying an unfamiliar intersection as the turn interval is significantly more difficult than the more automatic identification of a familiar intersection. |
| No lane change is required to get into the turning lane. | Although lane changes are common in this situation, lane changes were left out to simplify segmentation, allowing this situation to be covered in other scenarios (scenarios 4 and 6). |
| An oncoming vehicle is making a left turn into the inside lane (adjacent to the subject vehicle's destination lane). | Including a left-turning vehicle increases the difficulty associated with executing the right turn because the subject driver must also watch for potential conflicts with the left-turning vehicle. |

### Scenario Timeline

An approximate timeline showing the key temporal milestones for scenario 5 was calculated based on vehicle kinematics (figure 38). These milestones were used to make judgments about the pacing of tasks within segments and provide a basis for the overall sequencing of certain tasks. Some segments included an interval with a variable time component, which represented intervals that either were long enough to effectively provide unlimited time to perform tasks or of a duration that was determined external to vehicle kinematic factors (e.g., waiting for lead vehicle to turn).

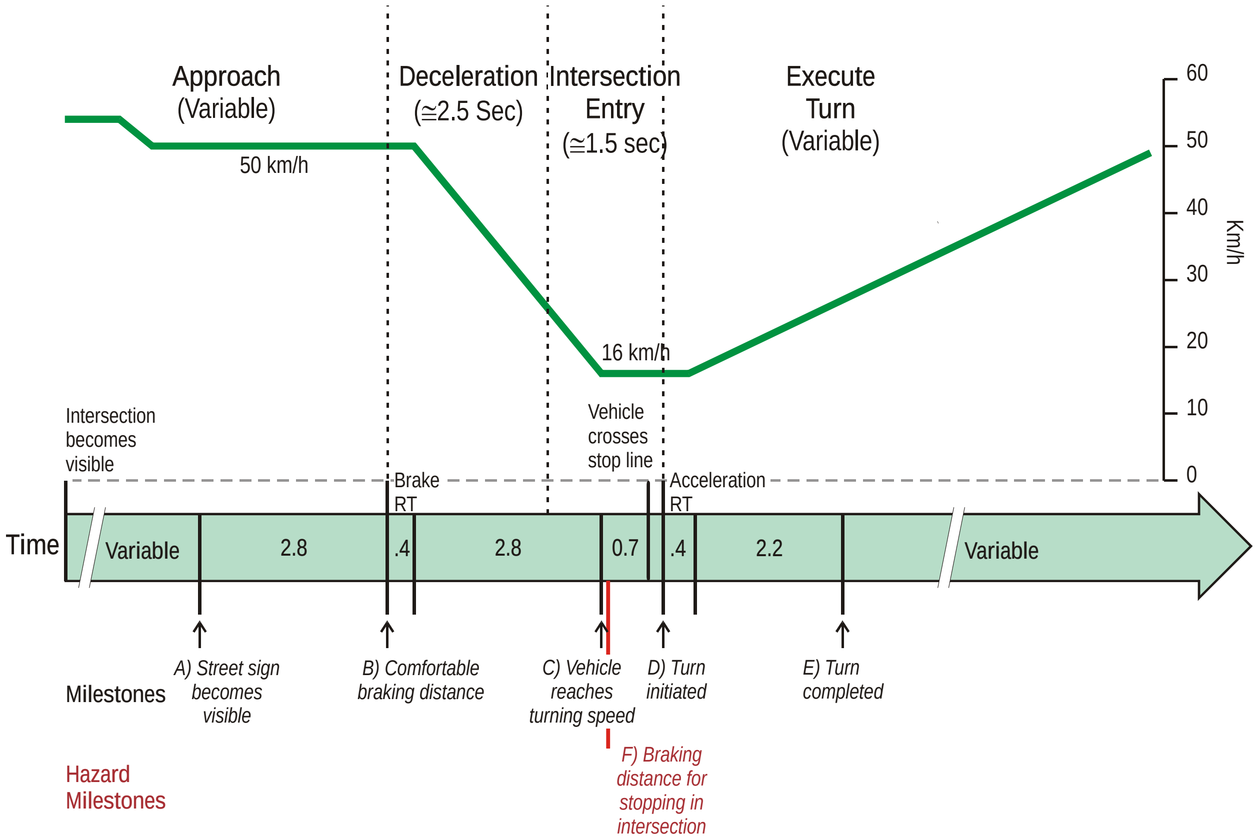



**Figure 38. Scenario 5—Right Turn on Green Light timeline of key segment phases duration and task milestones.**

## Task Analysis Table

The results of the task analysis organized by scenario segment are shown in the task analysis table (table 55). The task analysis results are duplicated for individual segments in the segment analyses tables in the next sections, which also discuss more fully the organization and content of the tasks and information processing subtasks.

**Table 55. Scenario 5—Right Turn on Green Light task analysis table.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **5.1 Approach** | | | |
| 5.1.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 5.1.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 5.1.3. Decelerate. | Visually assess distance to intersection. | Determine when vehicle is close enough to intersection to begin deceleration. | Coast (foot off accelerator) and/or gentle braking. |

**Table 55. Scenario 5—Right Turn on Green Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| 5.1.4. Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location, etc. | Determine if any nonroutine actions are required. | Head and eye movements for scanning. |
| 5.1.5. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 5.1.6. Determine if the light is about to change. | Scan visual scene for key cues (e.g., pedestrian signal, etc.). | Determine if cues suggest that the light will soon change. | Head and eye movements for scanning. |
| 5.1.7. Identify intersection as correct turn intersection. | Scan visual scene for indicator landmarks or street signs. | Identify unfamiliar intersection as correct one – read street signs. | Head and eye movements for scanning. |
| 5.1.8. Activate turn signal. | Visually assess distance to intersection. | Determine if vehicle is close enough to start signaling. | Activate turn signal control. |
| **5.2. Deceleration** | | | |
| 5.2.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 5.2.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 5.2.3. Begin deceleration. | Visually assess distance to intersection. | Determine when vehicle is close enough to intersection to begin deceleration. | Coast (foot off accelerator) and/or initiate braking. |
| 5.2.4. Observe vehicle deceleration trajectory. | Visually assess distance to intersection. | Determine that deceleration is sufficient for slowing to turning speed at the intersection. | Make necessary adjustments to deceleration rate. |
| 5.2.5. Maintain safe distance from following vehicles which are decelerating. | Visually assess distance and relative speed of following vehicle. | Determine if following-vehicle closing trajectory is safe. | Reduce deceleration if necessary.<br>Head and eye movements to observe rearview mirror. |
| 5.2.6. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| **5.3. Intersection Entry** | | | |
| 5.3.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 5.3.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 5.3.3. Decelerate to turning speed. | Visually assess distance to intersection. | Determine that deceleration is sufficient for slowing to turning speed or stopping in intersection. | Coast (foot off accelerator) and/or initiate gentle braking. |
| 5.3.4. Check for conflicts with following vehicle. | Visually assess trajectory of following vehicle. | Determine if distance and speed of following vehicle indicate potential conflict. | Head and eye movements to observe rearview mirror. |

**Table 55. Scenario 5—Right Turn on Green Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **5.3 Intersection Entry, *continued*** | | | |
| 5.3.5. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 5.3.6. Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | Determine if crossing vehicles are stopped or will stop in time. | Head and eye movements for observing cross traffic. |
| 5.3.7. Check for conflicts with left-turning vehicle. | Visually observe oncoming turning vehicle. | Determine if turning vehicle path will conflict.<br>Determine if turning driver is aware of subject vehicle's presence. | Head and eye movements for observing turning vehicle. |
| 5.3.8. Check for hazards in turn path. | Visually scan turn path to the right and intended lane (especially crosswalk). | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | Head and eye movements to view right-turn path. |
| **5.4. Execute Turn** | | | |
| 5.4.1. Accelerate to initiate turn and get up to speed. | View roadway to right. | Determine that acceleration is sufficient to get vehicle through the intersection in a timely manner. | Accelerate at necessary rate.<br>Head and eye movements to view roadway. |
| 5.4.2. Steer into turn. | View turn path. | Determine that vehicle trajectory and lane position are appropriate. | Steer to the right and make necessary adjustments to stay in lane. |
| 5.4.3.Check for hazards in turn path. | Visually scan turn path to the right (especially crosswalk for pedestrians and destination lane for stopped or parked cars). | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | Head and eye movements to view right-turn path. |
| 5.4.4. Check for conflicts with left-turning vehicle. | Visually assess trajectory of vehicle. | Determine if distance and trajectory are safe.<br>Confirm that vehicle does not try to cut into lane. | Adjust speed if necessary.<br>Head and eye movements to view vehicle. |
| 5.4.5. Continue accelerating up to speed. | Visually observe roadway. | Determine when traveling speed is reached. | Accelerate at needed rate.<br>Head and eye movements for viewing. |
| 5.4.6. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 5.4.7. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |

## Segment Analysis

### *Scenario 5, Segment 1, Approach*

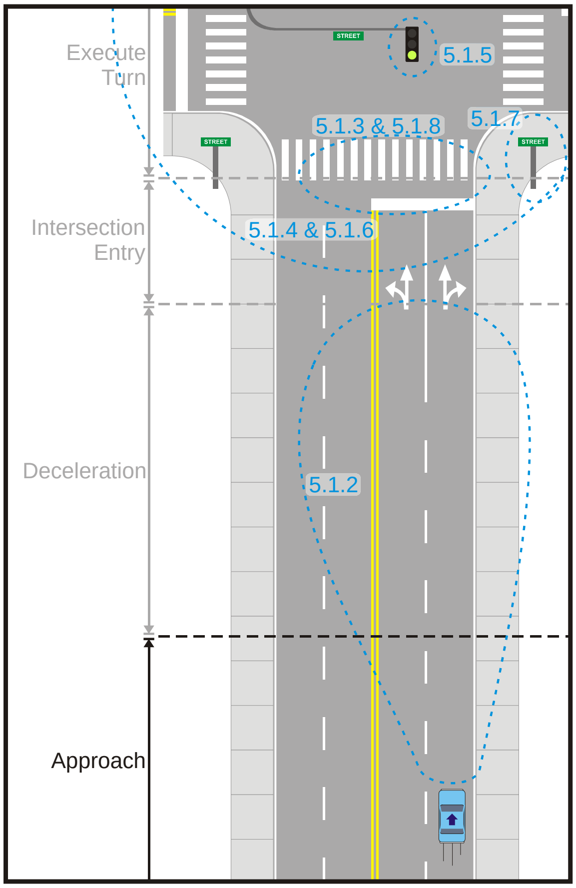
The *Approach* segment involves the subject vehicle traveling at full speed until the intersection is identified as the turn intersection and it is the appropriate time to begin decelerating. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 56. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 39 and table 57.

**Table 56. Scenario 5—Right Turn on Green Light *Approach* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 5.1.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 5.1.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | 7 | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 5.1.3 Decelerate. | Visually assess distance to intersection. | **4** | Determine when vehicle is close enough to intersection to begin deceleration. | **6** | Coast (foot off accelerator) and/or gentle braking. | **3** |
| 5.1.4 Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location, etc. | **6** | Determine if any nonroutine actions are required. | **6** | Head and eye movements for scanning. | **1** |
| 5.1.5 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 5.1.6 Determine if the light is about to change. | Scan visual scene for key cues (e.g., pedestrian signal, etc.). | **7** | Determine if cues suggest that the light will soon change. | **6** | Head and eye movements for scanning. | **1** |
| 5.1.7 Identify intersection as correct turn intersection. | Scan visual scene for indicator landmarks or street signs. | **7** | Identify unfamiliar intersection as correct one – read street signs. | **5** | Head and eye movements for scanning. | **1** |
| 5.1.8 Activate turn signal. | Visually assess distance to intersection. | **4** | Determine if vehicle is close enough to start signaling. | **4** | Activate turn signal control. | **2** |

Several points about the task analysis and workload estimates warrant discussion. The first is that the deceleration that takes place in task 5.1.3 (*decelerate*) is not the same as the deceleration in the next segment, which slows the vehicle to turning speed. Rather, the task 5.1.3 deceleration is just general deceleration that should be part of any approach to an intersection.[9] Another point is that task 5.1.7 (*identify intersection as turn intersection*) is a new task that is not indicated or suggested by any of the task analysis sources used (e.g., McKnight and Adams, 1970),[9] but instead is included because it is required by the scenario assumptions. Finally, task 5.1.6 (*determine if the light is about to change*) can range in difficulty based on the degree to which direct information is or is not available. For example, pedestrian walk signals can make the perceptual task into a simple inspection task (workload demand = 3) rather than a potentially complicated visual search task (workload demand = 7). The more demanding version was selected in keeping with the overall goals of addressing the worst-case scenarios.

**Scenario 5, Segment 1 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 39. Scenario 5—Right Turn on Green Light *Approach* segment diagram.**

**Table 57. Scenario 5—Right Turn on Green Light *Approach* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **5.1 Approach** | **Time** *Start* … *End* |
| 5.1.1 Maintain safe lane position. | F |
| 5.1.2 Check surround for unsafe situations. | S |
| 5.1.3 Decelerate. | S |
| 5.1.4 Identify intersection characteristics. | S |
| 5.1.5 Observe status of light. | ← S → |
| 5.1.6 Determine if the light is about to change. | S |
| 5.1.7 Identify intersection as correct turn intersection. | F |
| 5.1.8 Activate turn signal. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Frequent perceptual tasks involving scanning or reading in 5.1.2, 5.1.4, 5.1.6, and 5.1.7.
- Frequent cognitive tasks involving evaluation or judgment of several factors in 5.1.3, 5.1.4, and 5.1.6.
- Task 5.1.7 is a demanding forced-paced task that must be completed in a relatively short period of time.

***Mitigating factors:***

- Most of the difficult tasks are self-paced.
- Many tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 5.1.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Task 5.1.7 (*identify intersection as turn location*) is forced-paced because it is constrained by the fact that when an intersection is unfamiliar to the driver, this task cannot be performed until the street signs are readable, yet the task must be performed before it is too late to decelerate safely. Similarly, task 5.1.8 (*activate signal*) is also forced-paced because it must follow task 5.1.7, but precede *deceleration*.

In the task ordering, tasks 5.1.7 and 5.1.8 are confined to the latter parts of the segment because the subject driver has to be close enough to the intersection to read the street signs. In addition, because tasks 5.1.3 through 5.1.6 are self-paced, there are no barriers to performing them in advance of task 5.1.7 as long as the intersection is visible. Also, these are tasks that the subject driver would have to perform regardless of whether the driver was turning at this intersection or continuing straight. Thus, it makes sense that they would be done early. Finally, task 5.1.5 (*observe status of light*) can logically occur over a range of time.

### *Scenario 5, Segment 2, Deceleration*

The *Deceleration* segment involves the interval from where the subject vehicle begins to decelerate until the vehicle slows to near turning speed before entering the intersection. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 58. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 40 and table 59.

**Table 58. Scenario 5—Right Turn on Green Light *Deceleration* segment tasks and information processing subtasks.**

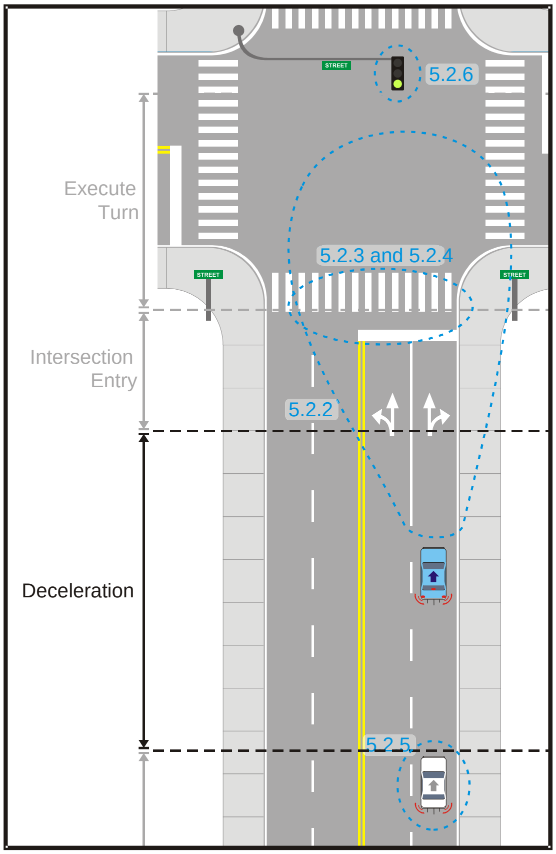
| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 5.2.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 5.2.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 5.2.3 Begin deceleration. | Visually assess distance to intersection. | **4** | Determine when vehicle is close enough to intersection to begin deceleration. | **6** | Coast (foot off accelerator) and/or initiate braking. | **3** |
| 5.2.4 Observe vehicle deceleration trajectory. | Visually assess distance to intersection. | **4** | Determine that deceleration is sufficient for slowing to turning speed at the intersection. | **6** | Make necessary adjustments to deceleration rate. | **3** |
| 5.2.5 Maintain safe distance from decelerating following vehicles. | Visually assess distance and relative speed of following vehicle. | **4** | Determine if following-vehicle closing trajectory is safe.* | **5** | Reduce deceleration if necessary. Head and eye movements to observe rearview mirror. | **3** |
| 5.2.6 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |

* Difficulty in this subtask is increased by value of 1 because of degraded information.

It is noteworthy that task 5.2.5 (*maintain safe distance from decelerating following vehicle*) cognitive subtask was treated as involving the evaluation of a single dimension (workload estimate = 4), rather than as the evaluation of multiple dimensions (workload estimate = 6) based on relative speed and distance. The reason is that evidence suggests that drivers may evaluate time-to-arrival as a single integrated variable (*tau*) rather than as separate speed and distance components.[11] Also, the estimated workload value for the cognitive element of this task was incremented by a value of 1, because determining the closing trajectory of the following vehicle is more difficult to accomplish using the degraded indirect visual information available from the rearview mirror. Note that this task is further complicated because the following vehicle's speed is also changing; however, the difficulty level was incremented only once to reflect these factors.

Note also that although the subject driver may have determined in the previous segment that the light will not change to yellow soon, it is still necessary to check the traffic signal sometime during this segment to ensure that the driver did not misjudge the light duration or that the light status is not about to change.

**Scenario 5, Segment 2 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 40. Scenario 5—Right Turn on Green Light *Deceleration* segment diagram.**

**Table 59. Scenario 5—Right Turn on Green Light *Deceleration* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **5.2 Deceleration** | **Time** *Start* → *End* |
| 5.2.1 Maintain safe lane position. | F |
| 5.2.2 Check surround for unsafe situations. | S |
| 5.2.3 Begin deceleration. | F |
| 5.2.4 Observe vehicle deceleration trajectory. | S |
| 5.2.5 Maintain safe distance from decelerating following vehicles. | S |
| 5.2.6 Observe status of light. | ← S → |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 5.2.1, 5.2.2, 5.2.4, and 5.2.5.
- Several demanding cognitive tasks involving either evaluation or judgment of multiple simultaneous factors (5.2.3 and 5.2.4.) or a single factor under increased difficulty (5.2.5).

***Mitigating factors:***

- Most of the difficult tasks are self-paced.
- Most tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 5.2.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Also, task 5.2.3 (*begin decelerating*) is forced-paced because the subject driver has a limited amount of time to decide to decelerate before the vehicle is too close to the stop line to permit safe or comfortable deceleration.

Regarding the task ordering, task 5.2.3 must come first because it initiates deceleration (the segment driving objective) while the other tasks are essentially ongoing throughout the segment. The exception is task 5.2.6 (*observe status of light*), which is temporally discrete and can occur over a range of time.

### *Scenario 5, Segment 3, Intersection Entry*

The *Intersection Entry* segment involves the subject vehicle decelerating to turning speed and entering the intersection in preparation for turning. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 60. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 41 and table 61.

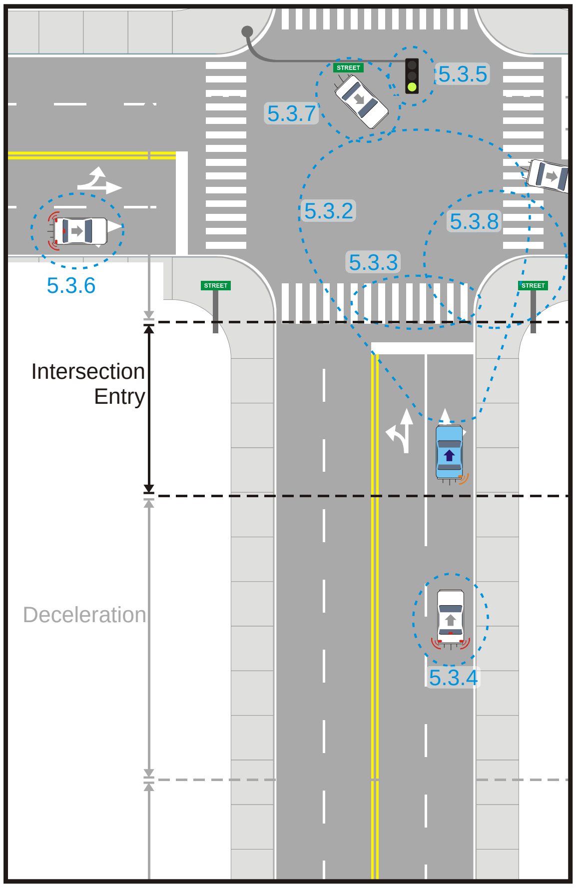
**Table 60. Scenario 5—Right Turn on Green Light *Intersection Entry* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 5.3.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 5.3.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 5.3.3 Decelerate to turning speed. | Visually assess distance to intersection. | **4** | Determine that deceleration is sufficient for slowing to turning speed or stopping in intersection. | **6** | Coast (foot off accelerator) and/or continue gentle braking. | **3** |
| 5.3.4 Check for conflicts with following vehicle. | Visually assess trajectory of following vehicle. | **4** | Determine if distance and speed of following vehicle indicate potential conflict.* | **5** | Head and eye movements to observe rearview mirror. | **1** |
| 5.3.5 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 5.3.6 Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | **5** | Determine if crossing vehicles are stopped or will stop in time. | **4** | Head and eye movements for observing cross traffic. | **1** |
| 5.3.7 Check for conflicts with left-turning vehicle. | Visually observe oncoming turning vehicle. | **4** | Determine if turning vehicle path will conflict. Determine if turning driver is aware of subject vehicle's presence. | **6** | Head and eye movements for observing turning vehicle. | **1** |
| 5.3.8 Check for hazards in turn path. | Visually scan turn path to the right and intended lane (especially crosswalk). | **7** | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | **4** | Head and eye movements to view right-turn path. | **1** |

* Difficulty in this subtask is increased by value of 1 because of degraded information.

The decision regarding whether the turn can be made without coming to a complete stop is made during this segment. Because the subject vehicle has the green light and right of way for turning into the closest lane, this decision mainly involves confirming that no hazards are in the way (tasks 5.3.5 through 5.3.7) and that the light remains green. Consequently, there is no separate decision task; the decision follows from the outcome of tasks 5.3.5 through 5.3.7. Note also that there is no continue into intersection task as in other scenarios. This task was omitted because the subject vehicle does not have to go as far into the intersection. Omitting this task also reduces the number of tasks in this segment.

**Scenario 5, Segment 3 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 41. Scenario 5—Right Turn on Green Light *Intersection Entry* segment diagram.**

**Table 61. Scenario 5—Right Turn on Green Light *Intersection Entry* segment of relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **5.3 Intersection Entry** | **Time** *Start* → *End* |
| 5.3.1 Maintain safe lane position. | F (start to end) |
| 5.3.2 Check surround for unsafe situations. | S (start to end) |
| 5.3.3 Decelerate to turning speed. | S (start to end) |
| 5.3.4 Check for conflicts with following vehicle. | S (start to end) |
| 5.3.5 Observe status of light. | S (first quarter) |
| 5.3.6 Check for red-light-running cross traffic. | F (second quarter) |
| 5.3.7 Check for conflicts with left-turning vehicles. | F (third quarter) |
| 5.3.8 Check for hazards in turn path. | F (last quarter) |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 5.3.1 through 5.3.4.
- Forced-paced conduct of 5.3.1 and 5.3.6 through 5.3.8.
- Several demanding cognitive tasks involving either evaluation or judgment of multiple simultaneous factors (5.3.3 and 5.3.7.) or a single factor under increased difficulty (5.3.4).
- Several demanding perceptual tasks involving visual scanning (5.3.2 and 5.3.8) or monitoring traffic (5.3.6).
- Information sources are widely distributed.
- A high number of tasks overall.
- High time pressure.

***Mitigating factors:***

- None.

Several assumptions make this decision process more complicated. One assumption is that cross traffic is moving and in the process of slowing to a stop, which makes task 5.3.6 (*check for red-*

*light-running cross traffic*) more difficult because it requires the subject driver to determine whether the slowing vehicles are stopping rather than simply checking if the vehicles are stopped at the intersection. Another complicating aspect is the assumption that an oncoming vehicle is making a left turn into the inside right-going lane. This situation requires that the subject driver monitor the path of the turning vehicle to ensure that the oncoming turning vehicle will not encroach into the subject vehicle's turn path (task 5.3.7). Finally, the estimated workload value for task 5.3.4 (*maintain safe distance from decelerating following vehicle)* cognitive subtask was incremented by a value of 1, because this task is made more difficult with the degraded indirect visual information from the rearview mirror.

*Task Pacing and Timing*—Task 5.3.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Also, tasks 5.3.6 through 5.3.8 are forced-paced because the rapidly approaching intersection and crosswalk limit the time available to check for these hazards in time to take evasive action.

Regarding the task ordering, tasks 5.3.1 through 5.3.4 are concurrent and ongoing throughout the segment. Although task 5.3.5 (*observe status of light*) is self-paced and can occur over a range of time, this task was positioned near the start of the segment by default, because the time available to perform the other tasks is limited by the rapidly approaching intersection. The other tasks (5.3.5 through 5.3.8) are sequential, and they are depicted in the order that they are most likely to be performed.

### *Scenario 5, Segment 4, Execute Turn*

The *Execute Turn* segment involves the actions related to initiating and completing the right turn. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 62. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 42 and table 63.

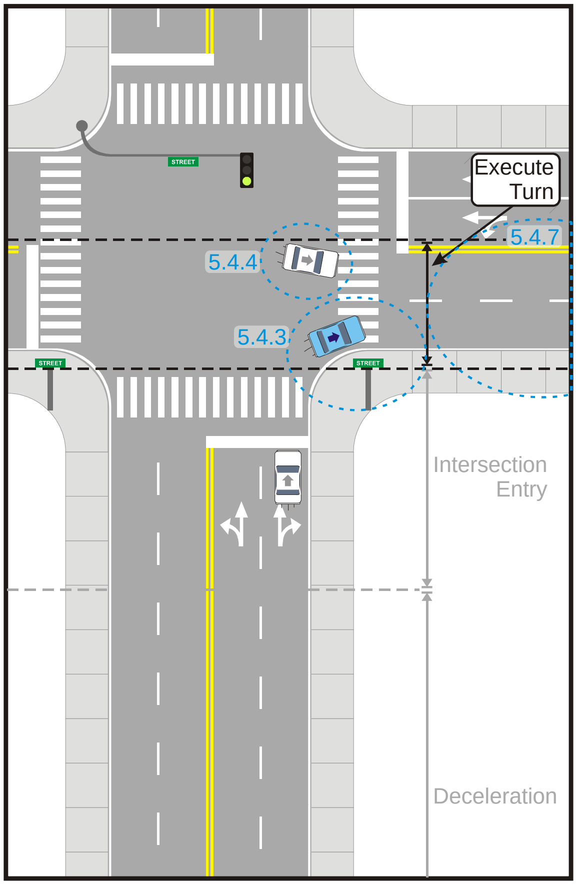
**Table 62. Scenario 5—Right Turn on Green Light *Execute Turn* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 5.4.1 Accelerate to initiate turn. | View roadway to right. | **3** | Determine that acceleration is sufficient to get vehicle through the intersection in a timely manner. | **4** | Accelerate at necessary rate. Head and eye movements to view roadway. | **3** |
| 5.4.2 Steer into turn. | View turn path. | **3** | Determine that vehicle trajectory and lane position are appropriate. | **6** | Steer to the right and make necessary adjustments to stay in lane. | **3** |
| 5.4.3 Check for hazards in turn path. | Visually scan turn path to the right (especially crosswalk for pedestrians and destination lane for stopped or parked cars). | **7** | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | **4** | Head and eye movements to view right-turn path. | **1** |
| 5.4.4 Check for conflicts with left-turning vehicle. | Visually assess trajectory of vehicle. | **4** | Determine if distance and trajectory are safe. Confirm that vehicle does not try to cut into lane. | **6** | Adjust speed if necessary. Head and eye movements to view vehicle. | **3** |
| 5.4.5 Continue accelerating up to speed. | Visually observe roadway. | **3** | Determine when traveling speed is reached. | **2** | Accelerate at necessary rate. Head and eye movements for viewing. | **3** |
| 5.4.6 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 5.4.7 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |

There are several noteworthy points in this segment. The first is that task 5.4.3 (*check for hazards in turn path*) is duplicated from the previous segment, which occurs shortly before. The reason for this is that in the previous segment this task was part of the criterion for deciding whether or not it was safe to continue directly into the turn, whereas in the present segment this task acts as a safety check for hazards. Another point is that task 5.4.5 (*continue accelerating up to speed*) is simply a continuation of task 5.4.1 in the new lane.

One aspect that makes this segment more complicated than others is that an oncoming vehicle is in the process of making a left turn into the inside right-going lane. This action requires that the subject driver monitor the path of the turning vehicle to make sure that the oncoming turning vehicle will not encroach into the subject vehicle's turn path (task 5.4.4).

**Scenario 5, Segment 4 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 42. Scenario 5—Right Turn on Green Light *Execute Turn* segment diagram.**

**Table 63. Scenario 5—Right Turn on Green Light *Execute Turn* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **5.4 Execute Turn** | **Time** *Start* → *End* |
| 5.4.1 Accelerate to initiate turn. | F (start) |
| 5.4.2 Steer into turn. | F (start) |
| 5.4.3 Check for hazards in turn path. | F (start) |
| 5.4.4 Check for conflicts with left-turning vehicle. | S (start to middle) |
| 5.4.5 Continue accelerating up to speed. | F (end) |
| 5.4.6 Maintain safe lane position. | F (end) |
| 5.4.7 Check surround for unsafe situations. | S (end) |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 5.4.1 through 5.4.4.
- Most of the tasks are forced-paced.

***Mitigating factors:***

- Most of the tasks are routine, automatic activities.

*Task Pacing and Timing*—Tasks 5.4.1 (*accelerate to initiate turn*), 5.4.2 (*steer into turn*), 5.4.5 (*continue accelerating*), and 5.4.6 (*lane maintenance*) are forced-paced because they are part of the ongoing task of driving. Task 5.4.3 (*check for hazards in the turn path*) is forced-paced because drivers only have a brief time to perform this task before the turn is complete.

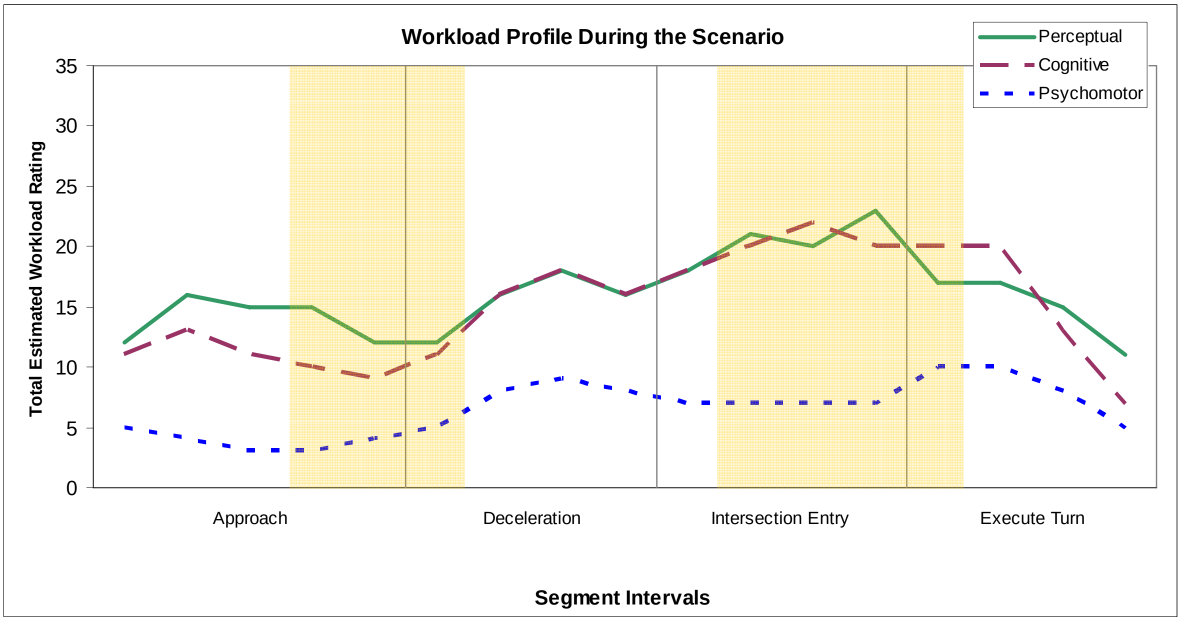
In the task ordering, the tasks are mostly concurrent, except for the division between the actual turn maneuver and getting up to speed after the subject vehicle is in the new lane. The one exception is task 5.4.4 (*check for conflicts with left-turning vehicle*). This task overlaps between the two stages because of the possibility that the left-turning driver may be unaware of the subject vehicle (e.g., if it is in the blind spot), and will try to change into the subject vehicle's lane.

**Scenario-Wide Analysis**

To help identify potential information processing bottlenecks in this scenario, workload estimates from all the segments were combined into a single scenario-wide workload profile that provides a general indication of where the areas of high workload demands are likely to be.

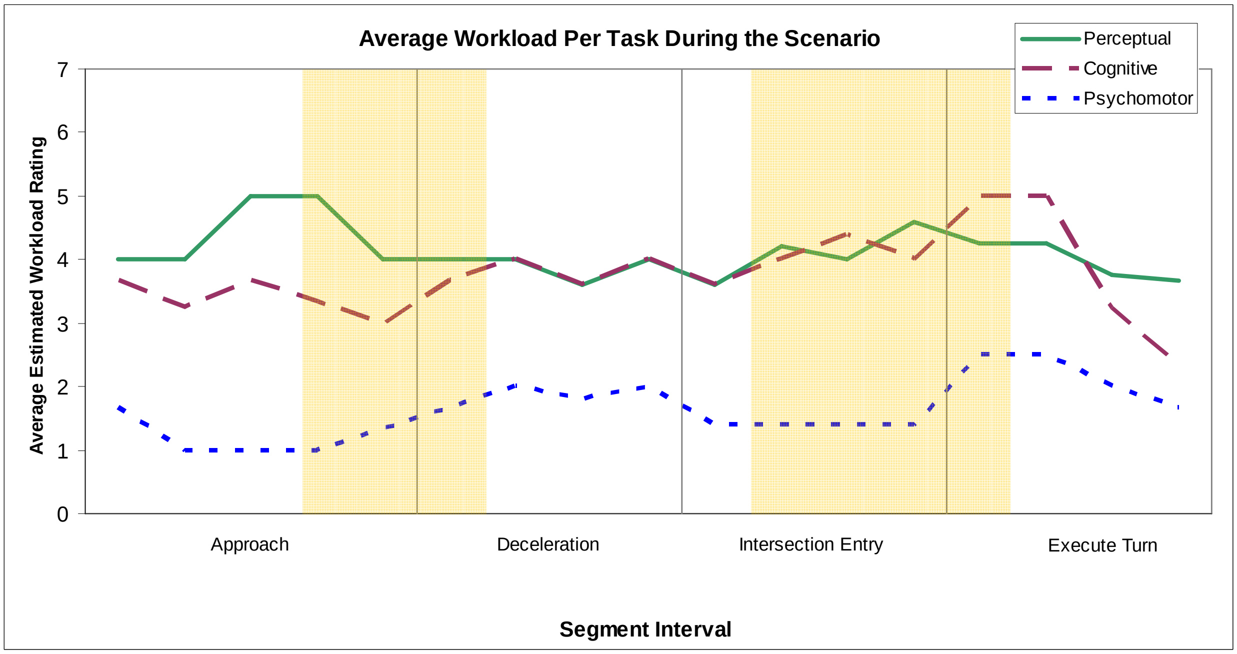
Figure 43 shows the summed workload estimates (separately for each information processing subtask) in each segment interval for the entire scenario. Also, the intervals in which key tasks are forced-paced are shaded in orange. As indicated by figure 43, the workload peaks at moderate levels for both the perceptual and cognitive elements during the *Intersection Entry* segment. Relative to other scenarios, there are also moderate levels of combined perceptual demands in all the segments and moderate levels of cognitive workload in the *Deceleration* and *Execute Turn* segments.

Figure 44, which displays the average workload estimate of all the tasks in play during a particular segment interval, shows that the peaks during the *Intersection Entry* segment in figure 43 arise from several tasks combined rather than just a few difficult tasks, although both the perceptual and cognitive subtasks in this segment do have relatively high average workload estimates. Otherwise, the average workload levels peak during the *Approach* segment for perceptual subtasks and peak during the initial part of the *Execute Turn* segment cognitive subtasks.




Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph shows the overall level of workload associated with a segment.

**Figure 43. Scenario 5—Right Turn on Green Light total estimated workload ratings for all tasks in each scenario segment.**




Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph generally represents the overall level of difficulty associated with the tasks in a segment.

**Figure 44. Scenario 5—Right Turn on Green Light average estimated workload ratings per task for each scenario segment.**

### *Information Processing Bottlenecks*

Information about the combined and average workload ratings, pacing of key tasks, and nature of bottlenecks for each segment is shown in table 64. Only information that represents potential problems is listed; blank cells indicate that no substantive issues occurred for a particular segment or cell. Following the table lists key information processing bottlenecks identified in each of the segments.

**Table 64. Scenario 5—Right Turn on Green Light combined and average workload ratings, pacing of key tasks, and nature of bottlenecks that indicate potential problems for each scenario segment.**

| Segment | Combined Workload | Average Workload | Pacing of Key Tasks | Nature of Bottlenecks |
|---|---|---|---|---|
| Approach | Moderate perceptual workload. | High perceptual workload. | Forced-pacing of key tasks. | Frequent perceptual tasks involving scanning or reading. |
| Deceleration | Moderate perceptual and cognitive workload. | | | Concurrent and continuous conduct of several demanding cognitive tasks involving either evaluation or judgment of single or multiple factors. |
| *Intersection Entry* | Moderate perceptual and cognitive workload. | High perceptual and cognitive workload. | Forced-pacing of key tasks. | Concurrent and continuous conduct of a high number of tasks, including several perceptual and cognitive tasks with high workload, distributed information sources, and high time pressure. |
| *Execute Turn* | Moderate perceptual and cognitive workload. | High cognitive workload. | Forced-pacing of some key tasks. | Concurrent and continuous conduct of several demanding cognitive tasks involving either evaluation or judgment of multiple factors. |

*Approach* nature of bottleneck: Visual demands:

- There is moderate combined and high average perceptual subtask workload involving some overlapping visual scanning and reading tasks. The difficulty of the activities in this segment is increased by the forced-pacing of the task involving identification of the intersection as the correct turn intersection.

*Deceleration* nature of bottleneck: Several concurrent tasks:

- Combined workload is high for perceptual and cognitive subtasks; however, this reality is offset by self-pacing of most of these tasks.

*Intersection Entry* nature of bottleneck: High time pressure for several tasks:

- A high number of demanding tasks are concurrent and draw on information distributed throughout the visual scene. In addition, a relatively high number of those tasks must also be performed under high time pressure.

*Execute Turn* nature of bottleneck: Concurrent tasks:

- Concurrent demanding cognitive subtasks take place during the initial part of the segment. These effects are mitigated somewhat because most of these tasks are routine, automatic activities.

## SCENARIO 6—RIGHT TURN ON RED LIGHT

### Description

This scenario involves the subject vehicle making a right turn on a red light after changing lanes to get into the right lane. Figure 45 shows the scenario diagram and provides additional details regarding the scenario. Briefly described, this scenario involves the subject driver identifying the intersection as the turn location and then the driver quickly changes lanes to get into the correct turn lane before decelerating to a stop at the intersection. Following this action, the subject driver advances into the crosswalk to get a better view of oncoming right-traveling traffic and waits until it is safe to go before executing the turn.

This scenario was divided into six segments (*Approach*, *Prepare for Lane Change*, *Execute Lane Change*, *Stop*, *Prepare for Turn/Intersection Entry*, and *Execute Turn*). The primary bases for parsing the scenario into these particular segments were that each segment had a different overall driving goal and most segments had different speed characteristics (table 65).

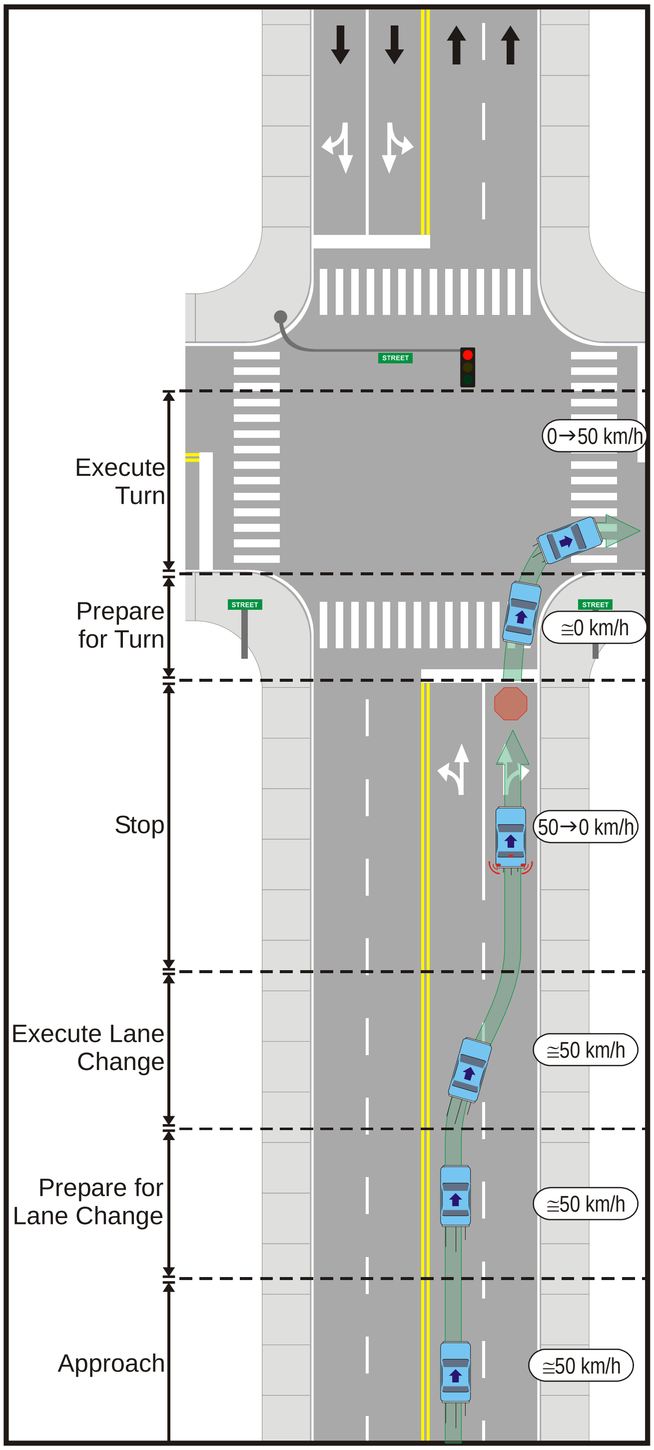
**Table 65. Scenario 6—Right Turn on Red Light driving objectives and speed characteristics for each scenario segment as a basis for the scenario partitioning.**

| Segment | Driving Objectives | Speed Characteristics |
|---|---|---|
| *Approach* | Identify upcoming intersection as the location of the turn. | Traveling at full speed. |
| *Prepare for Lane Change* | Determine if a lane change is feasible/safe. | Traveling near full speed. |
| *Execute Lane Change* | Maneuver into right lane. | Traveling near full speed with speed adjustments. |
| *Stop* | Stop at the intersection. | Controlled deceleration. |
| *Prepare for Turn/ Intersection Entry* | Get into position to turn. Decide that it is safe to turn. | Slow advance into position. |
| *Execute turn* | Make the turn. | Turning and accelerating up to speed. |

The relevant crash data for this scenario involving lane changes and right turns are discussed in scenario 4—Straight on Green Light and scenario 5—Right Turn on Green Light. The key problems for lane changes are that the tasks associated with determining whether it is safe to change lanes in the *Prepare for Lane Change* segment appear to be performance bottlenecks, especially with the inherent time limitations created by the approaching intersection. In addition, the relative prevalence of driver distraction, but not visual obstruction, in right-turn crashes suggests that the cognitive subtasks in the *Intersection Entry* segment are likely to be primary sources of difficulty during the preparation for the turn.

Figure 45 shows the scenario 6 diagram and lists the details.

**Scenario 6 Diagram**




- Segments are demarked by dotted lines.
- Approximate speed in km/h is indicated on the right.

**Note: Illustration dimensions and vehicle positions are not to scale.**

**Scenario Details**

**Activity**:
Right Turn on a Red Light

**Scenario Segments:**
- Approach
- Prepare for Lane Change
- Execute Lane Change
- Stop
- Prepare for Turn/Intersection Entry
- Execute Turn

**Intersection Configuration**:
Four-lane urban signalized intersection *without* a dedicated left-turn lane or a left-turn signal.

**Traffic Volume:**
Moderate (driving speeds are at speed limit and other lead/following/adjacent vehicles are present).

**Assumptions/Complicating Factors**:
- The turn intersection is familiar to the subject vehicle driver.
- There are no following or lead vehicles in the subject vehicle's originating lane.
- The driver must change lanes to get into the turning lane.
- There is a following vehicle in the destination lane but no lead vehicle.
- There are right-traveling vehicles in both the inside and outside lanes.

**Figure 45. Scenario 6—Right Turn on Red Light scenario diagram, details, and assumptions.**

Several assumptions were made regarding the situational aspects of the scenario. The justifications for these are summarized in figure 45 and more fully described in table 66.

**Table 66. Scenario 6—Right Turn on Red Light assumptions and corresponding justifications.**

| Assumption | Justification |
|---|---|
| The turn intersection is familiar to the subject vehicle driver. | The driver simply has to recognize the intersection as the correct turn intersection, which provides some variation from other scenarios. |
| There are no following or lead vehicles in the subject vehicle's originating lane. | This situation provides some variety across scenarios. |
| The driver must change lanes to get into the turning lane. | This situation increases the difficulty of this scenario. |
| There is a following vehicle in the destination lane but no lead vehicle. | This situation increases the difficulty of the lane-change-related activities and it also provides some variation from the lane change conditions in scenario 4. |
| There are right-traveling vehicles in both the inside and outside lanes. | This situation makes the gap judgments and turn execution more difficult by requiring the subject driver to check for potential conflicts with drivers in both right-traveling lanes. |

## Scenario Timeline

An approximate timeline showing the key temporal milestones for scenario 6 was calculated based on vehicle kinematics (figure 46). These milestones were used to make judgments about the pacing of tasks within segments and to provide a basis for the overall sequencing of certain tasks. Some segments included an interval with a variable time component, which represented intervals that were either long enough to effectively provide unlimited time to perform tasks or of a duration that was determined external to vehicle kinematic factors (e.g., waiting for lead vehicle to turn).

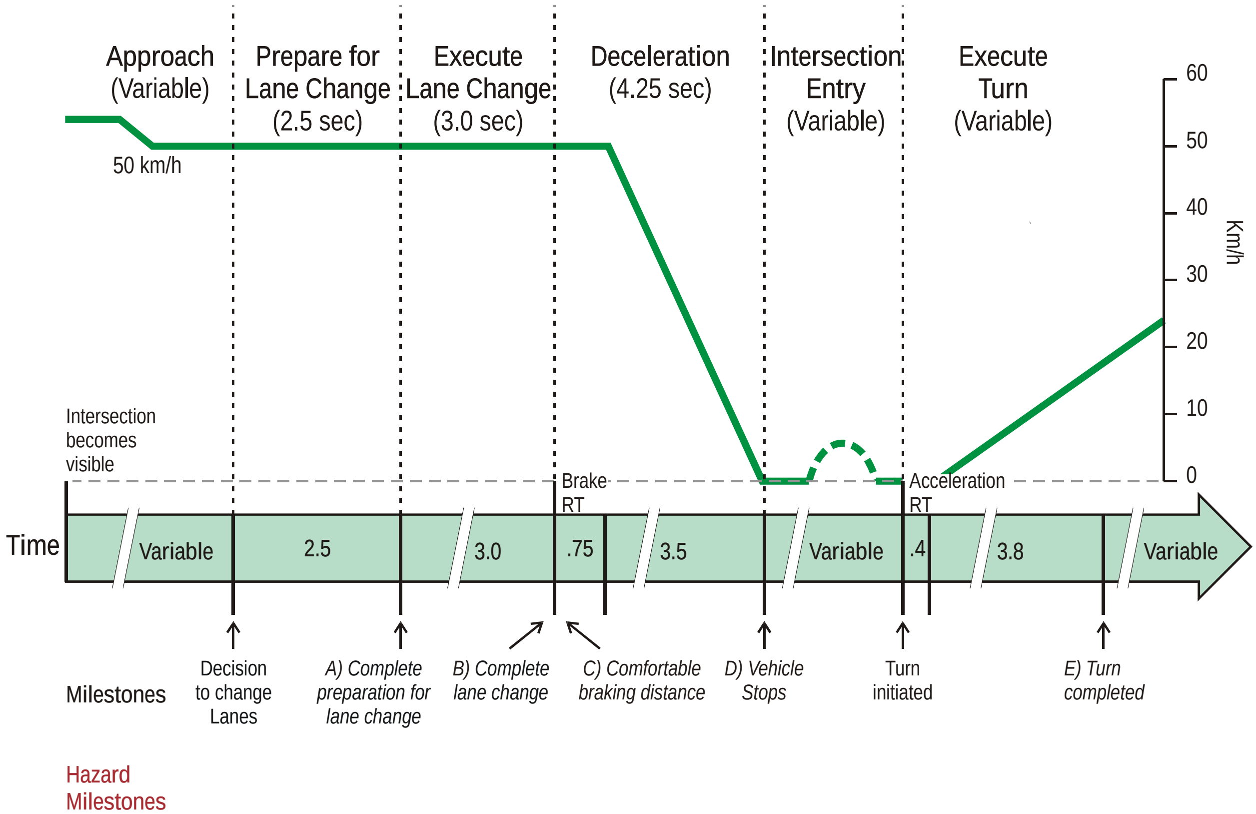



**Figure 46. Scenario 6—Right Turn on Red Light Scenario timeline depicting key segment phases duration and event/task milestones.**

### Task Analysis Table

The results of the task analysis organized by scenario segment are shown in the task analysis table (table 67). The task analysis results are duplicated for individual segments in the segment analyses tables in next sections, which also more fully discuss the organization and content of the tasks and information processing subtasks.

**Table 67. Scenario 6—Right Turn on Red Light task analysis table.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **6.1 Approach** | | | |
| 6.1.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 6.1.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 6.1.3. Decelerate. | Visually assess distance to intersection. | Determine when vehicle is close enough to intersection to begin deceleration. | Coast (foot off accelerator) and/or gentle braking. |

**Table 67 Scenario 6—Right Turn on Red Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **6.1 Approach, *continued*** | | | |
| 6.1.4. Identify intersection as correct turn intersection. | View visual scene for indicator landmarks or street signs. | Recognize familiar intersection as correct turn intersection. | Head and eye movements for scanning. |
| 6.1.5. Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location, etc. | Determine if any nonroutine actions are required. | Head and eye movements for scanning. |
| 6.1.6. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| **6.2. Prepare for Lane Change** | | | |
| 6.2.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 6.2.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 6.2.3. Decide whether lane change is legally permissible (e.g., lane markings are not solid). | Scan for signs prohibiting lane change.<br>Visually observe pavement markings. | Make yes/no decision regarding legality based on observed information. | Head and eye movements to look for indicators. |
| 6.2.4. Confirm that there is no lead vehicle in right lane. | View right lane. | Identify if any lead vehicles are present in the right lane. | Head and eye movements for viewing right lane. |
| 6.2.5. Check rearview mirror for rear-approaching traffic. | Observe presence and relative speed of rear-approaching traffic. | Determine if there will be a potential conflict with rear-approaching traffic. | Head and eye movements to observe rearview mirror. |
| 6.2.6. Check blind spot for rear-approaching traffic in right lane. | Visually observe right lane over shoulder. | Identify if any vehicles are present. | Head and eye movements to perform shoulder check. |
| **6.3. Execute Lane Change** | | | |
| 6.3.1. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 6.3.2. Activate turn signal. | Locate the control (automatic behavior). | Identify which direction to activate the control (automatic behavior). | Activate turn signal control. |
| 6.3.3. Adjust vehicle speed to avoid conflicts with right-lane following vehicle traveling at constant speed. | Visually assess distance and relative speed of following vehicle in right lane. | Determine if distance and relative speed are safe. | Accelerate if necessary.<br>Head and eye movements to view vehicle. |
| 6.3.4. Change lane. | Visually observe vehicle lateral position. | Identify when vehicle is completely in new lane. | Steer into new lane and adjust vehicle position. |

**Table 67 Scenario 6—Right Turn on Red Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **6.4. Stop** | | | |
| 6.4.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 6.4.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 6.4.3. Maintain safe distance from decelerating following vehicle. | Visually assess distance and relative speed of following vehicle. | Determine if following-vehicle closing trajectory is safe. | Reduce deceleration if necessary. Head and eye movements to observe rearview mirror. |
| 6.4.4. Activate turn signal. | Visually assess distance to intersection. | Recognize that the vehicle is close enough to intersection to start signaling. | Activate turn signal control. |
| 6.4.5. Begin deceleration. | Visually assess distance to intersection. | Recognize that the vehicle is close enough to intersection to begin deceleration. | Coast (foot off accelerator) and/or initiate braking. |
| 6.4.6. Observe vehicle stopping trajectory. | Visually assess distance to intersection. | Determine if deceleration rate will lead to safely stopping at stop line. | Make necessary adjustments to deceleration rate. |
| 6.4.7. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 6.4.8. Stop. | Visually assess distance to stop line. | Identify when stop line is reached. | Fully press and hold brake. |
| **6.5. Prepare for Turn /Intersection Entry** | | | |
| 6.5.1. Check for conflicts with following vehicle. | Visually assess trajectory of following vehicle. | Determine if distance and speed of following vehicle indicate potential conflict. | Head and eye movements to observe rearview mirror. |
| 6.5.2. Make sure pedestrians/cyclists are not crossing or about to cross. | Look left and right along crosswalk. | Identify if pedestrians/cyclists are present. | Head and eye movements for viewing. |
| 6.5.3. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 6.5.4. Advance into the crosswalk. | Visually observe crosswalk. | Determine when vehicle is at an appropriate position for turning. | Slowly accelerate and brake. |
| 6.5.5. Look for gap in right-going traffic. | Visually monitor traffic. | Determine distance and speed of oncoming traffic. Determine if there is a gap sufficient for turning. | Head and eye movements to monitor oncoming traffic. |

**Table 67. Scenario 6—Right Turn on Red Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **6.5 Prepare for Turn /Intersection Entry, *continued*** | | | |
| 6.5.6. Check for right-traveling vehicles in inside lane changing to outside (conflicting) lane. | Monitor oncoming vehicles in inside lane. | Determine if vehicle is about to change lanes (e.g., turn signal on). | Head and eye movements to monitor oncoming traffic. |
| 6.5.7. Check for hazards in turn path. | Visually scan turn path to the right and intended lane (especially crosswalk). | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | Head and eye movements to view right-turn path. |
| **6.6. Execute Turn** | | | |
| 6.6.1. Accelerate to initiate turn. | View roadway to right. | Determine that acceleration is sufficient to get vehicle through the intersection in a timely manner. | Accelerate at necessary rate.<br>Head and eye movements to view roadway. |
| 6.6.2. Steer into turn. | View turn path. | Determine that vehicle trajectory and lane position are appropriate. | Steer to the right and make necessary adjustments to stay in lane. |
| 6.6.3.Check for hazards in turn path. | Visually scan turn path to the right and intended lane (especially crosswalk). | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | Head and eye movements to view right-turn path. |
| 6.6.4. Check for conflicts with vehicle in inside lane. | Visually assess trajectory of vehicle. | Determine if distance and trajectory are safe.<br>Confirm that vehicle does not try to cut into lane. | Head and eye movements to view vehicle.<br>Adjust speed if necessary. |
| 6.6.5. Continue accelerating up to speed. | Visually observe roadway. | Determine when traveling speed reached. | Accelerate at needed rate.<br>Head and eye movements for viewing. |
| 6.6.6. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 6.6.7. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 6.6.8. Maintain safe distance from following vehicle at constant speed. | Visually assess distance and relative speed of following vehicle. | Determine if following-vehicle closing trajectory is safe. | Increase acceleration if necessary.<br>Head and eye movements to observe rearview mirror. |

## Segment Analysis

### *Scenario 6, Segment 1, Approach*

The *Approach* segment involves the subject vehicle traveling at full speed until the intersection is identified as the turn intersection and the driver determines that a lane change is required to get into the turning lane. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 68. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 47 and table 69.

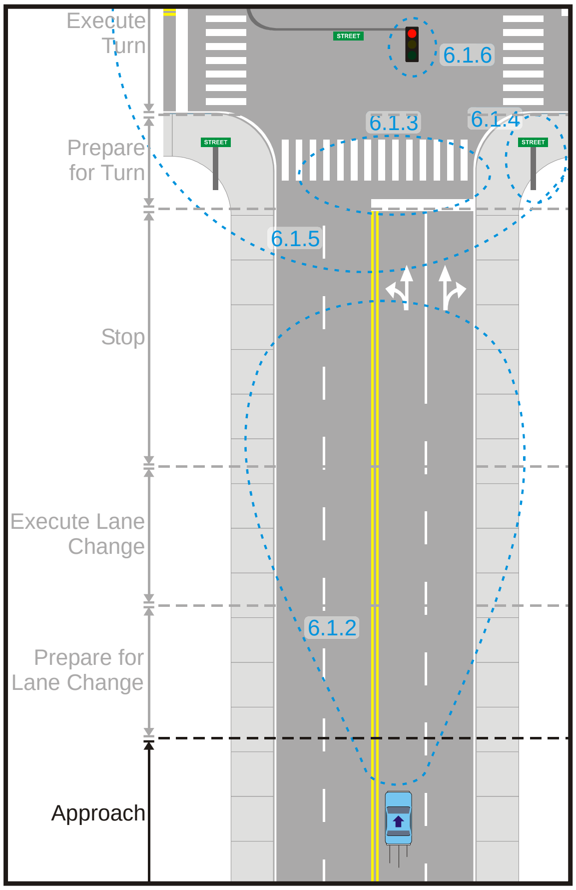
**Table 68. Scenario 6—Right Turn on Red Light *Approach* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 6.1.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 6.1.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 6.1.3 Decelerate. | Visually assess distance to intersection. | **4** | Determine when vehicle is close enough to intersection to begin deceleration. | **6** | Coast (foot off accelerator) and/or gentle braking. | **3** |
| 6.1.4 Identify intersection as correct turn intersection. | View visual scene for indicator landmarks or street signs. | **3** | Recognize familiar intersection as correct turn intersection. | **3** | Head and eye movements for scanning. | **1** |
| 6.1.5 Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location, etc. | **6** | Determine if any nonroutine actions are required. | **6** | Head and eye movements for scanning. | **1** |
| 6.1.6 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |

Several aspects of the task analysis and workload estimates warrant discussion. The first is that the deceleration that takes place in task 6.1.3 (*decelerate*) is not the same as the deceleration in the *Stop* segment (6.4), which stops the vehicle. Instead, the task 6.1.3 deceleration is just general deceleration that should be part of any approach to an intersection.[9] In addition, task 6.1.4 (*identify intersection as turn intersection*) is not directly specified in the task analysis references used,[9] but is instead included because logically it is a necessary part of this segment. Also, no task for activating the turn signal is defined in this segment because the subject vehicle must first change lanes (covered in the next two segments) before making the turn.

Another noteworthy point is that for this scenario the subject driver is familiar with the intersection. Here, the visual and cognitive demands are reduced because a direct search is not necessary to recognize the intersection.

**Scenario 6, Segment 1 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 47. Scenario 6—Right Turn on Red Light *Approach* segment scenario diagram.**

**Table 69 Scenario 6—Right Turn on Red Light *Approach* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **6.1 Approach** | **Time** *Start* → *End* |
| 6.1.1 Maintain safe lane position. | F |
| 6.1.2 Check surround for unsafe situations. | S |
| 6.1.3 Decelerate. | S |
| 6.1.4 Identify intersection as correct turn intersection. | S |
| 6.1.5 Identify intersection characteristics. | S |
| 6.1.6 Observe status of light. | ← S → |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Some perceptual tasks involving scanning in 6.1.2 and 6.1.5.
- Some cognitive tasks involving evaluation or judgment of multiple factors in 6.1.4 and 6.1.5.

***Mitigating factors:***

- Most of the tasks are self-paced.
- Most of the tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 6.1.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving, but the other tasks are self-paced.

In the task ordering, tasks 6.1.3 through 6.1.6 are sequential and can be performed in any order. The ordering chosen in this segment followed a logical sequence and was consistent with the ordering of similar tasks in the *Approach* segments in other driving scenarios included in this effort.

### *Scenario 6, Segment 2, Prepare for Lane Change*

The *Prepare for Lane Change* segment spans the time from when the subject driver determines that a lane change is required and gets into the turning lane to when the driver decides that it is legal and safe to make a lane change. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 70. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 48 and table 71.

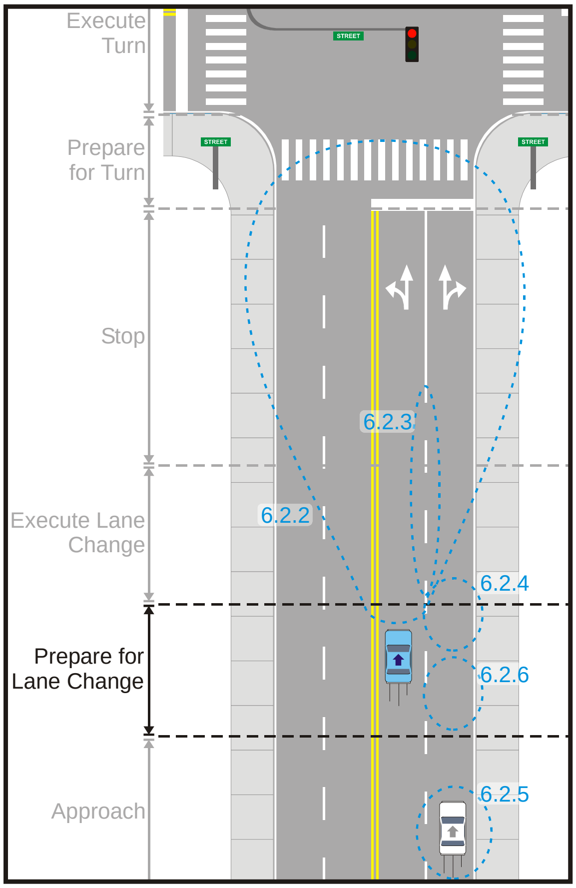
**Table 70. Scenario 6—Right Turn on Red Light *Prepare for Lane Change* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 6.2.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 6.2.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 6.2.3 Decide whether lane change is legally permissible (e.g., lane markings are not solid). | Scan for signs prohibiting lane change. Visually observe pavement markings. | **7** | Interpret information regarding legality based on observed information. | **5** | Head and eye movements for looking for indicators. | **1** |
| 6.2.4 Confirm that there is no lead vehicle in right lane. | View right lane. | **3** | Identify if any lead vehicles are present in the right lane. | **2** | Head and eye movements for viewing right lane. | **3** |
| 6.2.5 Check rearview mirror for rear-approaching traffic. | Observe presence and relative speed of rear-approaching traffic. | **4** | Determine if there will be a potential conflict with rear-approaching traffic.* | **5** | Head and eye movements to observe rearview mirror. | **1** |
| 6.2.6 Check blind spot for rear-approaching traffic in right lane. | Visually observe right lane over shoulder. | **1** | Identify if any vehicles are present. | **2** | Head and eye movements to observe and perform shoulder check. | **1** |

* Difficulty in this subtask is increased by a value of 1 because of degraded information.

Several points about the task analysis and workload estimation warrant discussion. First is the assumption that there is a vehicle behind the subject vehicle in the right destination lane but no vehicle in front. This assumption increases the level of difficulty to the lane-change maneuver while providing some variety from scenario 4, which had both lead and following vehicles. Consequently, task 6.2.4 (*confirm that there is no lead vehicle in right lane*) is easier to conduct than if the scenario included a lead vehicle but still must be performed because it is necessary to confirm that there is indeed no lead vehicle in the way. Another notable point is that there is no separate task defined for the actual decision about whether or not to change lanes. This decision process is the culmination of tasks (6.2.3 through 6.2.6) and the assumption is that the decision is an implicit result of resolving these tasks. Finally, the workload value of the task 6.2.5 (*check rearview mirror for rear-approaching traffic*) cognitive element was incremented by 1 because this task is made more difficult with the degraded indirect visual information from the rearview mirror.

**Scenario 6, Segment 2 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 48. Scenario 6—Right Turn on Red Light *Prepare for Lane Change* segment of scenario diagram.**

**Table 71. Scenario 6—Right Turn on Red Light *Prepare for Lane Change* segment of relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **6.2 Prepare for Lane Change** | **Time** *Start* → *End* |
| 6.2.1 Maintain safe lane position. | F |
| 6.2.2 Check surround for unsafe situations. | S |
| 6.2.3 Decide whether lane change is legally permissible. | F |
| 6.2.4 Confirm that there is no lead vehicle in right lane. | F |
| 6.2.5 Check rearview mirror for rear-approaching traffic. | F |
| 6.2.6 Check blind spot for rear-approaching traffic in right lane. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Perceptual tasks involving scanning in 6.2.2 and 6.2.3.
- Cognitive tasks involving interpretation of information in 6.2.3 and evaluation of a single factor under difficult conditions in 6.2.5.
- Tasks 6.2.3 through 6.2.6 are forced-paced and must be completed in a relatively short period of time.

***Mitigating factors:***

- None.

*Task Pacing and Timing*—Task 6.2.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Tasks 6.2.3 through 6.2.6 are forced-paced because they must be completed before initiating the lane change, which is itself constrained by the approaching intersection.

Regarding the task ordering, tasks 6.2.2 through 6.2.6 are shown as overlapping sequential tasks that follow the sequence described in the McKnight and Adams (1970) task analysis.(9) The reason for presenting them this way is that these tasks all involve visual information acquisition (which can only be done in sequence) that requires precise yet rapid deployment of visual gaze and attention to distributed locations throughout the visual scene. Consequently, there is likely to be some interference between these sequential tasks; however, because more time is available than in other time-limited segments with task interference (e.g., *Decision to Proceed* in scenario 3), the overlap was limited to adjacent tasks, rather than making them all simultaneous.

### *Scenario 6, Segment 3, Execute Lane Change*

The *Execute Lane Change* segment spans from the time that the subject vehicle initiates the lane change until the vehicle is established in the new lane. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 72, and the scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 49 and table 73.

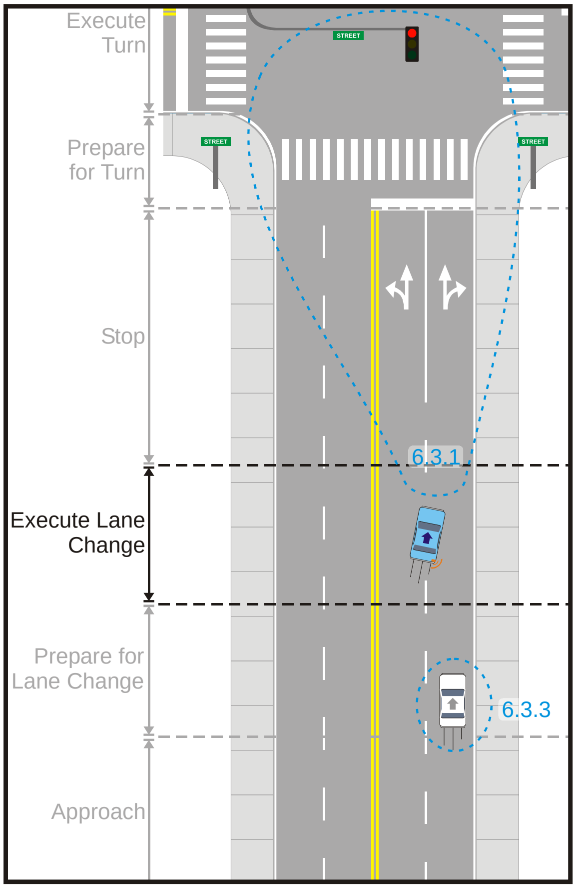
**Table 72. Scenario 6—Right Turn on Red Light *Execute Lane Change* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 6.3.1 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 6.3.2 Activate turn signal. | Locate the control (automatic behavior). | **1** | Identify which direction to activate the control (automatic behavior). | **1** | Activate turn signal control. | **1** |
| 6.3.3 Adjust vehicle speed to avoid conflicts with right-lane following vehicle traveling at constant speed. | Visually assess distance and relative speed of following vehicle in right lane. | **4** | Determine if distance and relative speed are safe.* | **7** | Accelerate if necessary. Head and eye movements to view vehicle. | **3** |
| 6.3.4 Change lane. | Visually observe vehicle lateral position. | **1** | Identify when vehicle is completely in new lane. | **2** | Steer into new lane and adjust vehicle position. | **3** |

* Difficulty in this subtask is increased by a value of 1 because of degraded information.

Several points about the task analysis and workload estimation warrant discussion. The first point is that task 6.3.2 (*activate turn signal*) was included in this segment because it should be done after determining that it is legal and safe to change lanes. Although it could have been included in the previous segment, it was included in this segment largely because research indicates that, in practice, many drivers do not activate the turn signal until the lane change is underway.[25] Also, the turn signal activation workload demands were assigned minimum values (workload = 1) because this is a highly learned automatic activity. Another point is that the *maintain safe lane position* task was not included in this segment because the subject vehicle is changing lanes during this segment. Finally, the estimated workload value for the task 6.3.3 cognitive element was incremented by a value of 1, because determining if the relative speed and distance of the following vehicle are safe is more difficult to do using the degraded indirect visual information from the rearview mirror.

**Scenario 6, Segment 3 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual task.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 49. Scenario 6—Right Turn on Red Light *Execute Lane Change* segment diagram.**

**Table 73. Scenario 6—Right Turn on Red Light *Execute Lane Change* segment of relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **6.3 Execute Lane Change** | **Time** *Start* → *End* |
| 6.3.1 Check surround for unsafe situations. | S (full duration) |
| 6.3.2 Activate turn signal. | F (start) |
| 6.3.3 Adjust vehicle speed to avoid conflicts with right-lane following vehicle traveling at constant speed. | F (full duration) |
| 6.3.4 Change lane. | F (latter part) |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Tasks 6.3.2 through 6.3.4 are forced-paced and must be completed in a relatively short period of time.

***Mitigating factors:***

- Most of the tasks are routine.

*Task Pacing and Timing*—Tasks 6.3.2 through 6.3.4 are forced-paced because they must be completed before the subject vehicle gets too close to the intersection.

In the task ordering, task 6.3.2 (*activate the turn signal*) initiates the segment, whereas task 6.3.3 (*adjust vehicle speed to avoid conflicts with decelerating right-lane following vehicle*) is ongoing both before and during the actual lane-change maneuver (task 6.3.4).

### *Scenario 6, Segment 4, Stop*

The *Stop* segment ranges from when the subject vehicle begins to decelerate after establishing itself in the new lane until the vehicle comes to a complete stop at the stop line. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 74. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 50 and table 75.

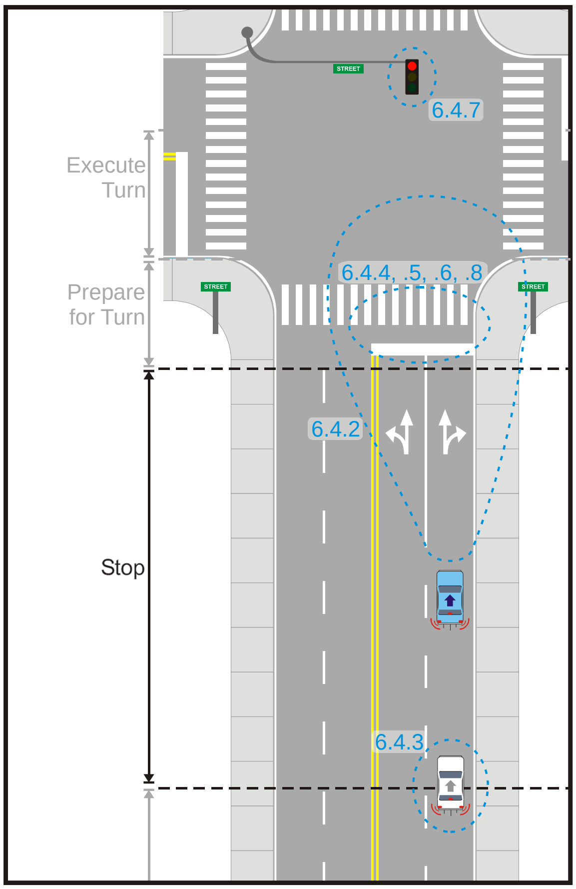
**Table 74. *Stop* Segment of Scenario 6—Right Turn on Red Light tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 6.4.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 6.4.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 6.4.3 Maintain safe distance from decelerating following vehicle. | Visually assess distance and relative speed of following vehicle. | **4** | Determine if following-vehicle closing trajectory is safe.* | **5** | Reduce deceleration if necessary. Head and eye movements to observe rearview mirror. | **3** |
| 6.4.4 Activate turn signal. | Visually assess distance to intersection. | **4** | Recognize that the vehicle is close enough to intersection to start signaling. | **3** | Activate turn signal control. | **2** |
| 6.4.5 Begin deceleration. | Visually assess distance to intersection. | **4** | Recognize that the vehicle is close enough to intersection to begin deceleration. | **3** | Coast (foot off accelerator) and/or initiate braking. | **3** |
| 6.4.6 Observe vehicle stopping trajectory. | Visually assess distance to intersection. | **4** | Determine if deceleration rate will lead to safely stopping at stop line. | **6** | Make necessary adjustments to deceleration rate. | **3** |
| 6.4.7 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 6.4.8 Stop. | Visually assess distance to stop line. | **4** | Identify when stop line reached. | **2** | Fully press and hold brake. | **2** |

* Difficulty in this subtask is increased by a value of 1 because of degraded information.

One assumption in this segment is that the subject vehicle is far enough away from the intersection that deceleration does not have to start until the lane change is complete. Also, task 6.4.4 (*activate turn signal*) may be unnecessary if the subject vehicle's signal did not automatically cancel following the lane change; however, this task was included to cover the situation in which it does cancel, and, more importantly, because the signal activation has a different purpose than in the previous segment. (signal for lane change versus signal for intersection turn). Also a simplified version of tasks 6.4.4 and 6.4.5 (*begin deceleration*) cognitive elements was assumed because by the time the subject vehicle completes the lane change, it is close enough to the intersection that it should be obvious that it is time to signal and decelerate at an aggressive rate (appendix A). Finally, the estimated workload value for the task 6.4.3 cognitive subtask was incremented by a value of 1, because determining if the relative speed and distance of the following vehicle are safe is more difficult to do using the degraded indirect visual information from the rearview mirror.

**Scenario 6, Segment 4 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 50. Scenario 6—Right Turn on Red Light *Stop* segment diagram.**

**Table 75. Scenario 6—Right Turn on Red Light *Stop* segment of relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **6.4 Stop** | **Time** *Start* → *End* |
| 6.4.1 Maintain safe lane position. | F |
| 6.4.2 Check surround for unsafe situations. | S |
| 6.4.3 Maintain safe distance from decelerating following vehicle. | S |
| 6.4.4 Activate turn signal. | F |
| 6.4.5 Begin deceleration. | F |
| 6.4.6 Observe vehicle stopping trajectory. | S |
| 6.4.7 Observe status of light. | ← S → |
| 6.4.8 Stop. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 6.4.1, 6.4.2, 6.4.3, and 6.4.6.
- Several demanding cognitive tasks involving either evaluation or judgment of multiple simultaneous factors (6.5.5 and 6.5.6) or a single factor under increased difficulty (6.5.3).
- A high number of tasks overall.

***Mitigating factors:***

- Most of the difficult tasks are self-paced.
- Several tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 6.4.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Also, tasks 6.4.4 (*activate turn signal*) and 6.4.5 (*begin decelerating*) are forced-paced because the intersection is rapidly approaching, and task 6.4.8 (*stop*) is forced-paced because the subject vehicle has to stop behind the stop line.

Regarding the task ordering, tasks 6.4.4 (*activate turn signal*) and 6.4.5 (*begin decelerating*) occur immediately and concurrently because the subject driver needs to start decelerating immediately and should signal the intention to turn as soon as possible. The next tasks—6.4.6

(*observe stopping trajectory*), and 6.4.8 (*stop*)—follow an obvious sequence, while the other tasks are essentially ongoing throughout the segment. The exception is task 6.4.7 (*observe status of light*), which is temporally discrete and can occur over a range of time.

### *Scenario 6, Segment 5, Prepare for Turn/Intersection Entry*

The *Prepare for Turn/Intersection Entry* segment involves the subject vehicle advancing into the crosswalk to get a better view of right-traveling traffic when it is safe to do so, and then monitoring traffic until there is a sufficient gap to make the right turn. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 76. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 51 and table 77.

**Table 76. Scenario 6—Right Turn on Red Light *Prepare for Turn/Intersection Entry* segment tasks and information processing subtasks.**

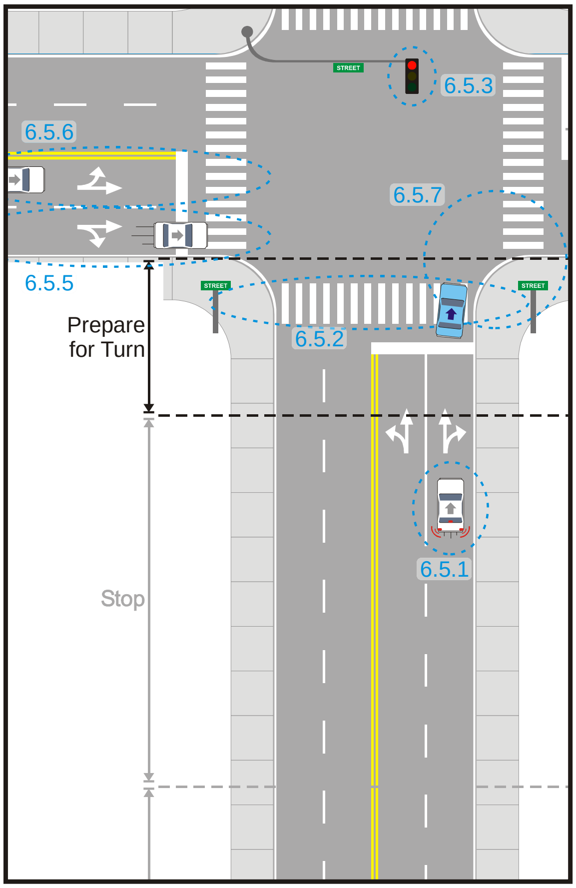
| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 6.5.1 Check for conflicts with following vehicle. | Visually assess trajectory of following vehicle. | **4** | Determine if distance and speed of following vehicle indicate potential conflict.* | **5** | Head and eye movements to observe rearview mirror. | **1** |
| 6.5.2 Make sure pedestrians/cyclists are not crossing or about to cross. | Look left and right along crosswalk. | **3** | Identify if pedestrians/cyclists are present. | **2** | Head and eye movements for viewing. | **1** |
| 6.5.3 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 6.5.4 Advance into the crosswalk. | Visually observe crosswalk. | **1** | Determine when vehicle is in an appropriate position for turning. | **4** | Slowly accelerate and brake. | **3** |
| 6.5.5 Look for gap in right-going traffic. | Visually monitor traffic. | **5** | Determine distance and speed of oncoming traffic.<br>Determine if there is a gap sufficient for turning. | **6** | Head and eye movements to monitor oncoming traffic. | **1** |
| 6.5.6 Check for right-traveling vehicles in inside lane changing to outside (conflicting) lane. | Monitor oncoming vehicles in inside lane. | **5** | Determine if vehicle is about to change lanes (e.g., turn signal on). | **6** | Head and eye movements to monitor oncoming traffic. | **1** |
| 6.5.7 Check for hazards in turn path. | Visually scan turn path to the right and intended lane (especially crosswalk). | **7** | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. | **4** | Head and eye movements to view right-turn path. | **1** |

* Difficulty in this subtask is increased by a value of 1 because of degraded information.

Task 6.5.3 (*observe status of the light*) is included for two reasons: Drivers need to know the traffic signal status to maintain awareness of the current situation and pedestrian/cyclist behavior may change depending on the light status (e.g., some pedestrians may run out into the crosswalk if the light is about to turn yellow in order to try to make it across at the last minute). Also note that there is no separate task defined for the actual decision regarding whether it is safe to turn.

This decision process is the culmination of tasks 6.5.5 through 6.5.7, and the assumption is that the decision is an implicit result of resolving these tasks. Finally, the estimated workload value for the task 6.5.1 cognitive subtask was incremented by a value of 1, because determining the trajectory of the following vehicle is more difficult to do using the degraded indirect visual information from the rearview mirror.

**Scenario 6, Segment 5 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 51. Scenario 6—Right Turn on Red Light *Prepare for Turn/Intersection Entry* segment of scenario diagram.**

**Table 77. Scenario 6—Right Turn on Red Light *Prepare for Turn / Intersection Entry* segment relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **6.5 Prepare for Turn / Intersection Entry** | **Time** *Start* → *End* |
| 6.5.1 Check for conflicts with following vehicle. | S |
| 6.5.2 Make sure pedestrians/cyclists are not crossing or about to cross. | S |
| 6.5.3 Observe status of light. | S |
| 6.5.4 Advance into the crosswalk. | S |
| 6.5.5 Look for gap in right-going traffic. | F |
| 6.5.6 Check for vehicles in inside lane changing to outside (conflicting) lane. | F |
| 6.5.7 Check for hazards in turn path. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 6.5.1, 6.5.5, 6.5.6, and 6.5.7 under high time pressure.
- The majority of the time in this segment is likely to be taken by forced-paced tasks that have relatively high perceptual workload (6.5.5, 6.5.6, and 6.5.7) and/or high cognitive workload (6.5.5 and 6.5.6).
- Task 6.5.6 represents a high-stress decision with possible severe consequences if done inaccurately.

***Mitigating factors:***

- Initial tasks are self-paced.

*Task Pacing and Timing*—Tasks 6.5.5 through 6.5.7 are forced-paced because the subject driver is limited in time because new gaps are continuously appearing and requiring evaluation, forcing the driver back to task 6.5.5 (*look for gap in traffic*). This step repeats until a safe gap is finally identified, then the driver is limited in time because the gap is rapidly approaching and the decision to turn must be completed before the lead safe-gap vehicle arrives at the intersection.

In the task ordering, task 6.5.2 (*check for conflicts with following vehicle*) is ongoing throughout the segment. Tasks 6.5.5 through 6.5.7 are concurrent because the driver must repeatedly cycle between evaluating new gaps as they become visible (task 6.5.2) and maintaining a current assessment of the situation (tasks 6.5.1, 6.5.6, and 6.5.7). The other tasks were ordered based on logical sequence: note that this sequence has no effect on combined or average workload levels because the tasks are all sequential.

### *Scenario 6, Segment 6, Execute Turn*

The *Execute Turn* segment involves the actions related to initiating and completing the right turn (it was determined in segment 5 that it was safe to turn) and getting up to speed in the new lane. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 78. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 52 and table 79.

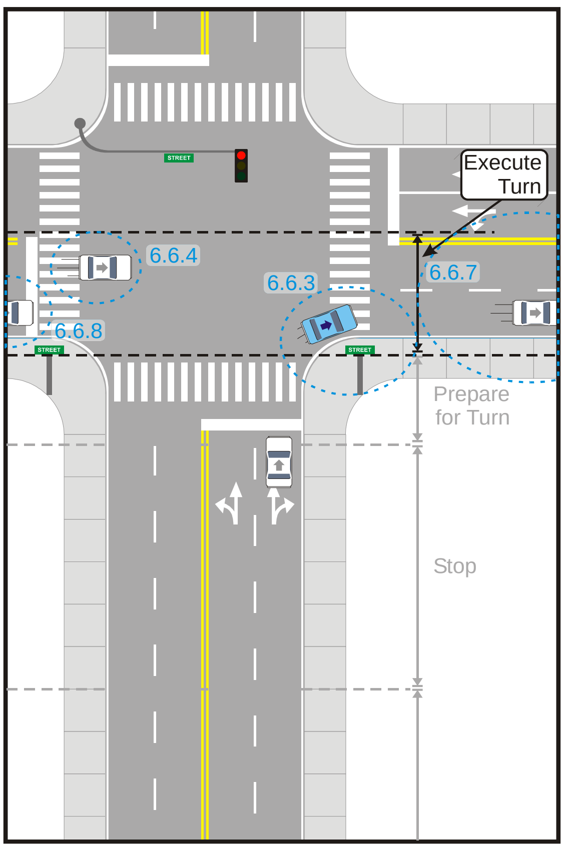
**Table 78. Scenario 6—Right Turn on Red Light *Execute Turn* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| 6.6.1 Accelerate to initiate turn and get up to speed. | View roadway to right. **3** | Determine that acceleration is sufficient to get vehicle through the intersection in a timely manner. **4** | Accelerate at necessary rate. Head and eye movements to view roadway. **3** |
| 6.6.2 Steer into turn. | View turn path. **3** | Determine that vehicle trajectory and lane position are appropriate. **6** | Steer to the right and make necessary adjustments to stay in lane. **3** |
| 6.6.3 Check for hazards in turn path. | Visually scan turn path to the right and intended lane (especially crosswalk). **7** | Determine if any pedestrians/cyclists or other hazards are in the crosswalk or about to enter. **4** | Head and eye movements to view right-turn path. **1** |
| 6.6.4 Check for conflicts with vehicle in inside lane. | Visually assess trajectory of vehicle. **4** | Determine if distance and trajectory are safe. Confirm that vehicle does not try to cut into lane. **6** | Adjust speed if necessary. Head and eye movements to view vehicle. **3** |
| 6.6.5 Continue accelerating up to speed. | Visually observe roadway. **3** | Determine when traveling speed is reached. **2** | Accelerate at necessary rate. Head and eye movements for viewing. **3** |
| 6.6.6 Maintain safe lane position. | Visually observe roadway ahead. **1** | Verify correct lane position. **1** | Make necessary adjustments to steering. **1** |
| 6.6.7 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. **4** | Head and eye movements for scanning. **1** |
| 6.6.8 Maintain safe distance from following vehicle at constant speed. | Visually assess distance and relative speed of following vehicle. **4** | Determine if following-vehicle closing trajectory is safe.* **5** | Increase acceleration if necessary. Head and eye movements to observe rearview mirror. **3** |

* Difficulty in this subtask is increased by a value of 1 because of degraded information.

There are several noteworthy points for this segment. The first is that task 6.6.3 (*check for hazards in turn path*) is duplicated from the previous segment, which occurs shortly before. The reason it is repeated here is that in the previous segment this task was part of the criterion for deciding whether it was safe to turn, whereas here this task acts as a safety check for hazards. Also, while the subject vehicle is in the process of turning, it is necessary to check for right-traveling vehicles in the inside lane changing into the subject vehicle's lane (even though this is an illegal maneuver in an intersection in most jurisdictions), in case they may not have noticed or expected the subject vehicle's turn. On a similar note, there is no need to watch for conflicts with a lead vehicle in this segment because the lead vehicle would be pulling away with a faster relative speed; however, it is especially necessary, to check for conflicts with the following vehicle which will also, initially, be traveling at a faster relative speed. Finally, the estimated workload value for the cognitive element of task 6.6.8 was incremented by a value of 1, because determining the closing trajectory of the following vehicle is more difficult to do using the degraded indirect visual information from the rearview mirror.

**Scenario 6, Segment 6 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 52. Scenario 6—Right Turn on Red Light *Execute Turn* segment diagram.**

**Table 79. Scenario 6—Right Turn on Red Light *Execute Turn* segment of relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **6.6. Execute Turn** | **Time** *Start* → *End* |
| 6.6.1 Accelerate to initiate turn and get up to speed. | F |
| 6.6.2 Steer into turn. | F |
| 6.6.3 Check for hazards in turn path. | F |
| 6.6.4 Check for conflicts with vehicle in inside lane. | S |
| 6.6.5 Continue accelerating up to speed. | F |
| 6.6.6 Maintain safe lane position. | F |
| 6.6.7 Check surround for unsafe situations. | S |
| 6.6.8 Maintain safe distance from following vehicle at constant speed. | S |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 6.5.1 through 6.5.4 and 6.6.4 through 6.6.8.
- Several of the tasks are forced-paced.
- There is a high number of tasks overall.
- The initial phase is a high-stress situation with possible severe consequences if conducted inaccurately.

***Mitigating factors:***

- Most of the tasks are routine, automatic activities.

*Task Pacing and Timing*—Tasks 6.6.1 (*accelerate to initiate turn*), 6.6.2 (*steer into turn*), 6.7.5 (*continue accelerating*), and 6.6.6 (*lane maintenance*) are forced-paced because they are part of the ongoing task of driving. Task 6.6.3 (*check for hazards in the turn path*) is forced-paced because drivers only have a brief time to perform this task before the turn is complete.

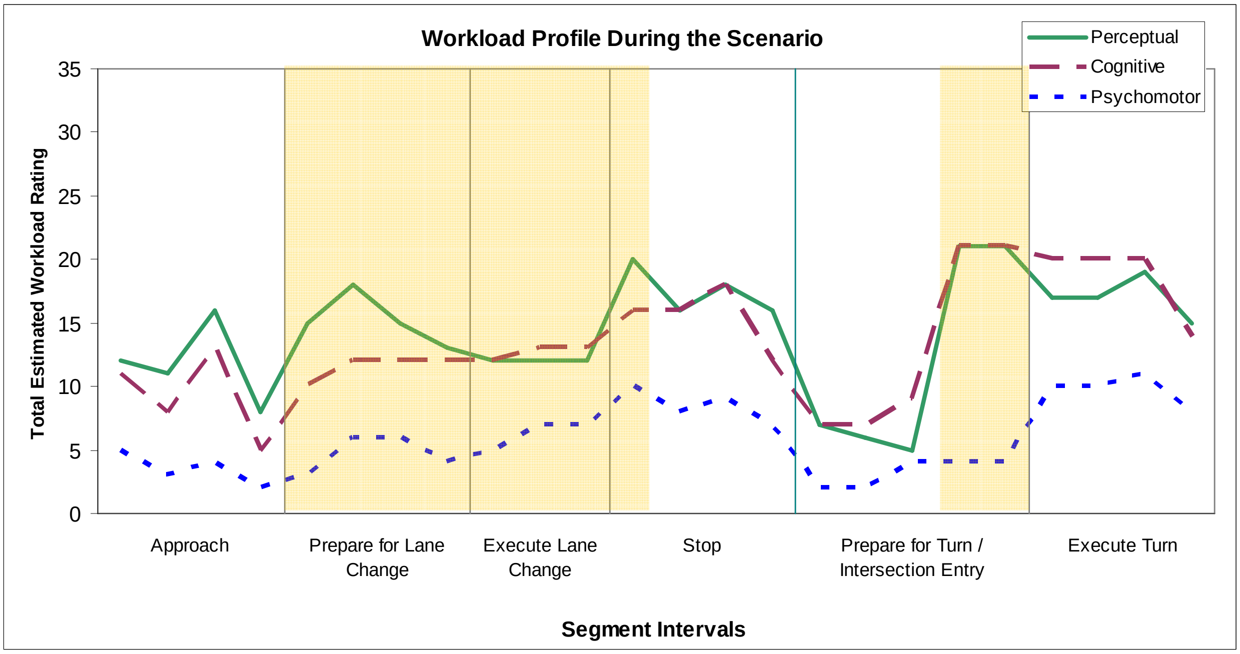
In the task ordering, the tasks are mostly concurrent except for the division between the actual turn maneuver and getting up to speed once in the new lane. The one exception is task 6.6.4 (*check for conflicts with vehicle in inside lane*), which overlaps between the two groups of tasks because of the possibility that the inside-lane driver may be unaware of the subject vehicle and will try to change into the subject vehicle's lane.

**Scenario-Wide Analysis**

To help identify potential information processing bottlenecks in this scenario, workload estimates from all the segments were combined into a single scenario-wide workload profile that provides a general indication of where the areas of high workload demands are likely to be.

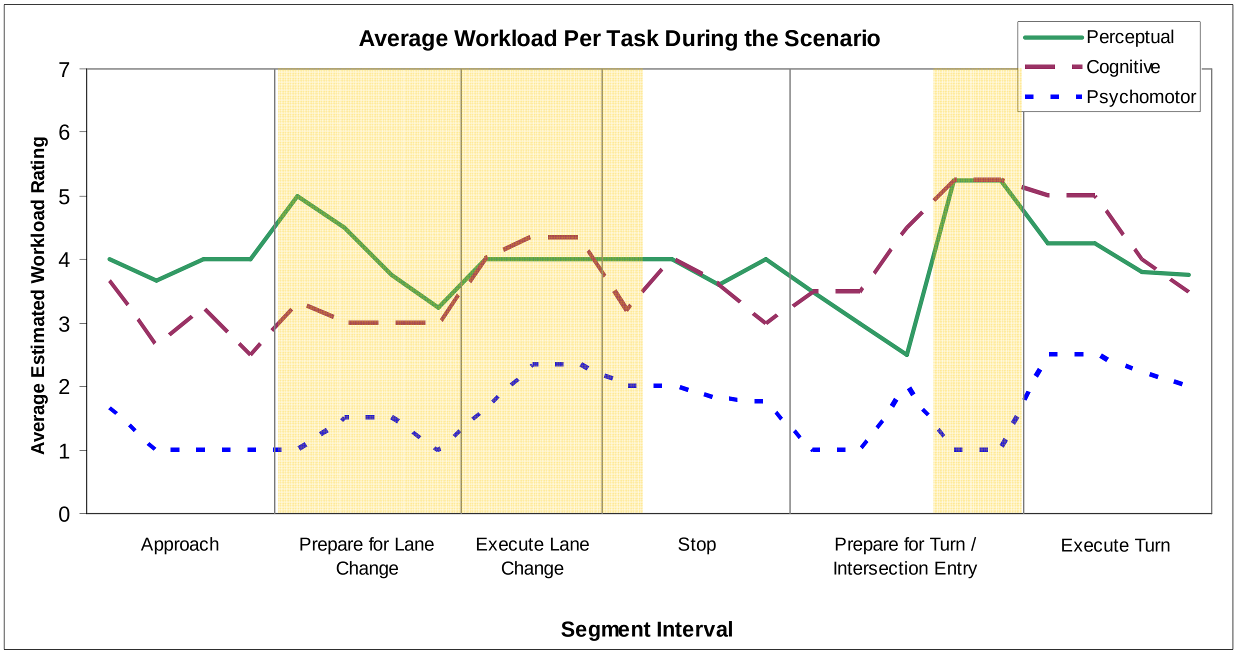
Figure 53 shows the summed workload estimates (separately for each information processing subtask) in each segment interval for the entire scenario. Also, the intervals in which key tasks are forced-paced are shaded in orange. As shown in figure 53, the workload peaks at moderate levels for both the perceptual and cognitive subtasks during the *Stop*, *Prepare for Turn*, and *Execute Turn* segments.

Figure 54, which displays the average workload estimate of all the tasks in play during a particular segment interval, shows that the peaks during the *Stop* segment in figure 53 arise from several tasks combined rather than just a few difficult tasks. In contrast, the peak during the *Prepare for Turn* segment arises from high average workload values. The elevated levels in the *Execute Turn* segment are likely due to a combination of both of these factors. Overall, average workload levels peak during the *Approach* segment for perceptual subtasks, and they peak during the *Prepare for Turn* and *Execute Turn* segments for both perceptual and cognitive subtasks.




Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph shows the overall level of workload associated with a segment.

**Figure 53. Scenario 6—Right Turn on Red Light total estimated workload ratings for all tasks in each scenario segment.**




Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph generally represents the overall level of difficulty associated with the tasks in a segment.

**Figure 54. Scenario 6—Right Turn on Red Light average estimated workload ratings per task for each scenario segment.**

### *Information Processing Bottlenecks*

Information about the combined and average workload ratings, pacing of key tasks, and nature of bottlenecks for each segment is shown in table 80. Only information that represents potential problems is listed; blank cells indicate that no substantive issues occurred for a particular segment or cell. The table is followed by a list of key information processing bottlenecks identified in each of the segments.

**Table 80. Scenario 6—Right Turn on Red Light combined and average workload ratings, pacing of key tasks, and nature of bottlenecks that indicate potential problems for each scenario segment.**

| Segment | Combined Workload | Average Workload | Pacing of Key Tasks | Nature of Bottlenecks |
|---|---|---|---|---|
| *Approach* | | | | Some perceptual tasks involving scanning or reading and cognitive tasks involve evaluation of multiple factors. |
| *Prepare for Lane Change* | | High perceptual workload. | Forced-pacing of several key tasks. | Rapid sequence of some perceptual and cognitive tasks with moderate to high workload that involve distributed information and high time pressure. |
| *Execute Lane Change* | | | Forced-pacing of key tasks. | Concurrent and continuous conduct of tasks under high time pressure. |
| *Stop* | Moderate perceptual and cognitive workload. | | Forced-pacing of some tasks. | A high number of tasks overall, with several concurrent tasks in the initial part involving moderate to high cognitive demands. |
| *Prepare for Turn* | Moderate perceptual and cognitive workload. | High perceptual and cognitive workload. | Forced-pacing of key tasks. | Concurrent and continuous conduct of some high-stress and demanding perceptual and cognitive subtasks under time pressure.<br>The information sources are widely distributed. |
| *Execute Turn* | Moderate perceptual and cognitive workload. | High perceptual and cognitive workload. | Forced-pacing of some key tasks. | Concurrent and continuous conduct of some high-stress and demanding perceptual and cognitive subtasks under time pressure. |

*Prepare for Lane Change* nature of bottleneck*:* High time pressure:

- A few tasks involving moderate to high perceptual and cognitive workload focus on obtaining information from the environment in order to decide whether or not a lane change can be made. These tasks must be performed precisely and in rapid succession under high time pressure because the time available to make the decision is limited by the approaching intersection.

*Execute Lane Change* nature of bottleneck*:* High time pressure:

- Concurrent and ongoing perceptual and cognitive tasks with moderate to high workload are conducted under time pressure because the subject vehicle must safely get into the new lane with sufficient time to perform the *Stop* tasks. These effects are mitigated somewhat because most of these tasks are routine, automatic activities.

*Stop* nature of bottleneck*:* A relatively high number of concurrent tasks:

- Combined workload is high in the initial part for perceptual and cognitive subtasks because several tasks run concurrently, and some with moderate to high perceptual or cognitive workload. These effects are offset, however, by the self-pacing and routine, automatic nature of most of these tasks.

*Prepare for Turn* nature of bottleneck*:* Concurrent high workload, high-stress tasks under time pressure:

- High combined and average perceptual and cognitive subtask workload involve continuous and concurrent tasks of moderate and high workload. These are also high-stress tasks that must be performed under time pressure, and they require information sampling that is widely distributed in the environment.

*Execute Turn* nature of bottleneck: Concurrent high workload, high-stress tasks under time pressure:

- The initial phase of this segment is somewhat of a continuation of the previous segment. Moderate combined and high average perceptual and cognitive *subtask* workload involves continuous and concurrent tasks of moderate and high workload. In addition, these initial tasks are high stress and must be performed under time pressure.

## SCENARIO 7—STOP ON RED LIGHT

### Description

This scenario involves the subject vehicle stopping at a red light. Figure 55 shows the scenario diagram and provides additional details regarding the scenario. Briefly described, this scenario involves the subject driver approaching the intersection and seeing that the light is red, decelerating to a stop, waiting, and then proceeding through the intersection once the light turns green and the lead vehicle goes.

This scenario was divided into three segments (*Approach*, *Stop*, and *Proceed Through Intersection*). The primary bases for parsing the scenario into these segments were that each segment had a different overall driving goal and each had different speed characteristics (table 81).

**Table 81. Scenario 7—Stop on Red Light driving objectives and speed characteristics for each scenario segment used as a basis for the scenario partitioning.**

| Segment | Driving Objectives | Speed Characteristics |
|---|---|---|
| *Approach* | Observe that the light is red. | Traveling at or near full speed. |
| *Stop* | Stop at the intersection. | Controlled deceleration. |
| *Proceed Through Intersection* | Continue driving. | Accelerate to full speed. |

The crash data related to this scenario indicate several characteristics relevant to the task analysis and configuration of this scenario. In particular, rear-end crashes made up 25.2 percent of all crashes in the 1991 GES data. GES data categorize this type of crash into two subtypes: lead-vehicle stationary (LVS) (16.1 percent of all rear-end crashes) and lead-vehicle moving (LVM) (9.2 percent of same).(21) Both subtypes are relevant in the current scenario: the LVS subtype is involved when the lead vehicle decelerates to a stop before being struck by the subject vehicle, and the LVM subtype is involved when the lead vehicle becomes struck while it is still moving. The most common causal factors in rear-end crashes included driver inattention (56.7 percent) and tailgating/unsafe passing (26.5 percent). These findings suggest that the tasks associated with the *Stop* segment are primary sources of difficulty for drivers.

Figure 55 shows the scenario 7 diagram and lists scenario details.

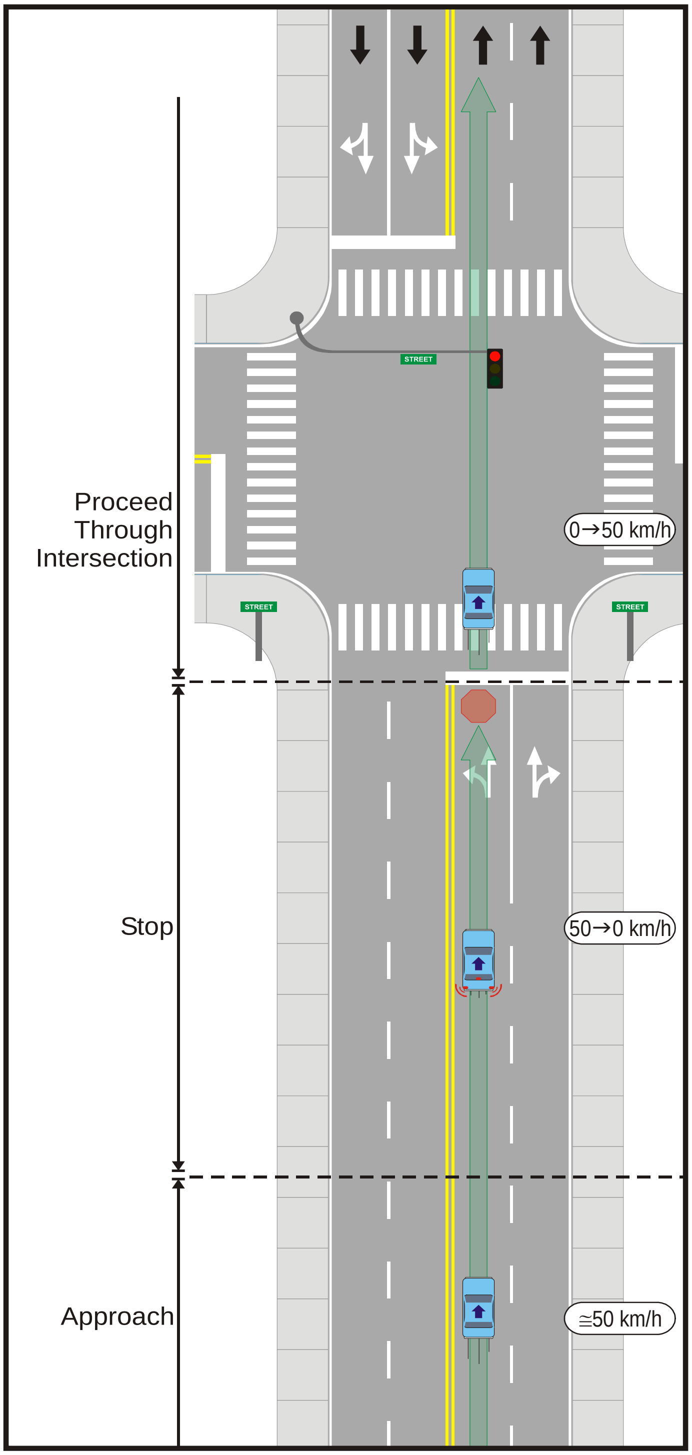
| Scenario 7 Diagram | Scenario Details |
|---|---|
| <br>• Segments are demarked by dotted lines.<br>• Approximate speed in km/h is indicated on the right.<br>**Note: Illustration dimensions and vehicle positions are not to scale.** | **Activity**:<br>Left Turn on a Green Light<br><br>**Scenario Segments:**<br>• Approach<br>• Stop<br>• Proceed Through Intersection<br><br>**Intersection Configuration**:<br>Four-lane urban signalized intersection *without* a dedicated left-turn lane or a left-turn signal.<br><br>**Traffic Volume:**<br>Moderate (driving speeds are at speed limit and other lead/following/adjacent vehicles are present).<br><br>**Assumptions/Complicating Factors**:<br>• The subject vehicle is following a vehicle and followed by another vehicle. |

**Figure 55. Scenario 7—Stop on Red Light diagram, details, and assumptions.**

Just one assumption was made regarding the situational aspects of the scenario. The justification for making this assumption is summarized in figure 55 and more fully described in table 82.

**Table 82. Scenario 7—Stop on Red Light assumptions and corresponding justifications.**

| Assumption | Justification |
|---|---|
| The subject vehicle is following a vehicle and followed by another vehicle. | Including this extra traffic makes the deceleration-related tasks more demanding. |

### Scenario Timeline

An approximate timeline showing the key temporal milestones for scenario 7 was calculated based on vehicle kinematics (see figure 56). These milestones were used to make judgments about the pacing of tasks within segments and to provide a basis for the overall sequencing of certain tasks. Most segments included an interval with a variable time component, which represented intervals that were either long enough to effectively provide unlimited time to perform tasks or of a duration that was determined external to vehicle kinematic factors (e.g., waiting for lead vehicle to go).

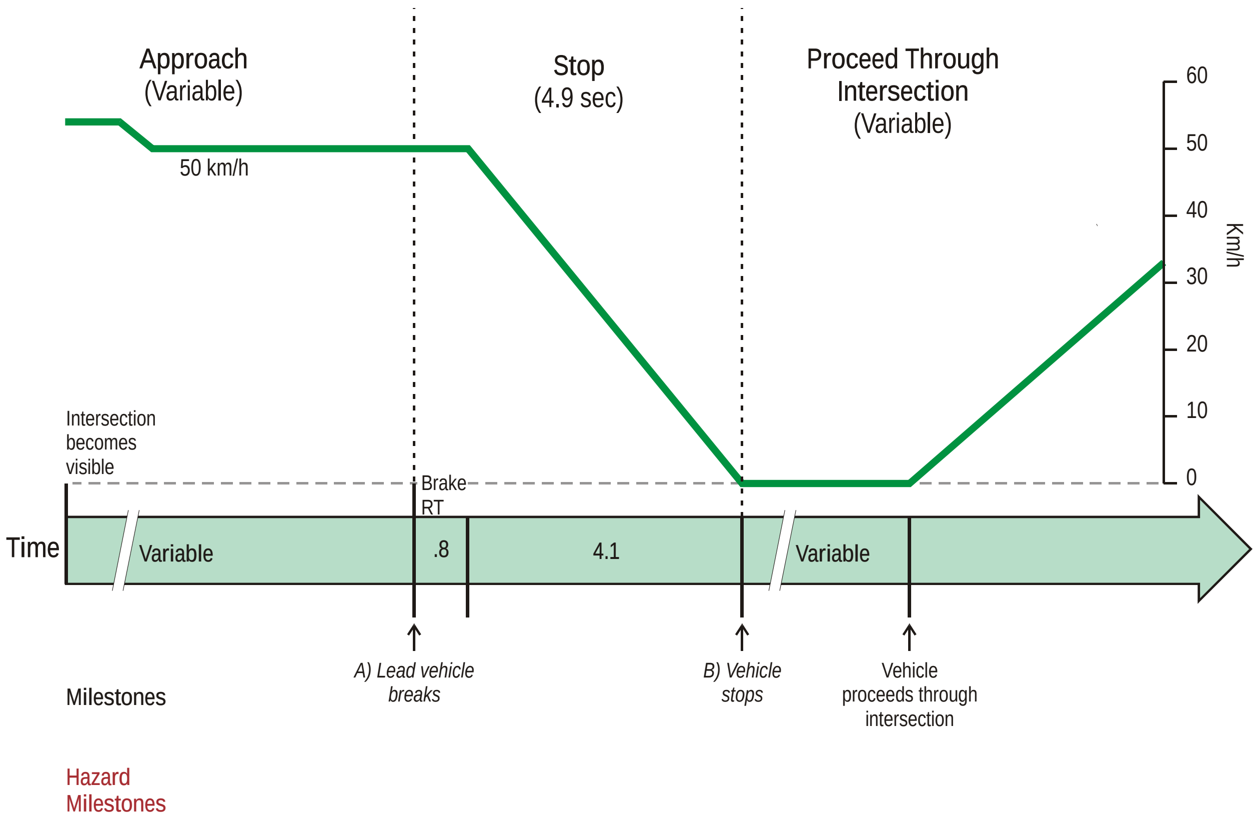



**Figure 56. Scenario 7—Stop on Red Light Scenario timeline depicting key segment phases duration and event/task milestones.**

## Task Analysis Table

The results of the task analysis organized by scenario segment are shown in the task analysis table (table 83). The task analysis results are duplicated for individual segments in the segment analyses tables in the next sections, which also more fully discuss the organization and content of the tasks and information processing subtasks.

**Table 83. Scenario 7—Stop on Red Light task analysis table.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **7.1 Approach** | | | |
| 7.1.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 7.1.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 7.1.3. Maintain safe distance from lead vehicle traveling at constant speed. | Visually assess distance and relative speed of leading vehicle. | Determine if lead-vehicle trajectory is safe. | Reduce speed if necessary.<br>Head and eye movements to view vehicle. |
| 7.1.4. Decelerate. | Visually assess distance to intersection. | Determine when vehicle is close enough to intersection to begin deceleration. | Coast (foot off accelerator) and/or gentle braking. |
| 7.1.5. Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal location, etc. | Determine if any nonroutine actions are required. | Head and eye movements for scanning. |
| 7.1.6. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| **7.2. Stop** | | | |
| 7.2.1. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 7.2.2. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |
| 7.2.3. Begin deceleration. | Detect lead vehicle brake lights. | Confirm that lead vehicle is stopping. | Coast (foot off accelerator) and/or initiate braking. |
| 7.2.4. Observe vehicle stopping trajectory. | Visually assess distance to intersection. | Determine if deceleration rate will lead to safely stopping in appropriate location. | Make necessary adjustments to deceleration rate. |
| 7.2.5. Maintain safe distance from decelerating lead vehicle. | Visually assess distance and relative speed of lead vehicle. | Determine if lead-vehicle trajectory is safe. | Increase deceleration if necessary.<br>Head and eye movements to view lead vehicle. |

**Table 83. Scenario 7—Stop on Red Light task analysis table, continued.**

| Task | Perceptual Subtasks | Cognitive Subtasks | Psychomotor Subtasks |
|---|---|---|---|
| **7.2 Stop, *continued*** | | | |
| 7.2.6. Maintain safe distance from decelerating following vehicles. | Visually assess distance and relative speed of following vehicle. | Determine if following-vehicle closing trajectory is safe. | Reduce deceleration if necessary.<br>Head and eye movements to observe rearview mirror. |
| 7.2.7. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 7.2.8. Stop. | Visually assess distance to lead vehicle. | Determine when lead vehicle is in appropriate location for stopping. | Fully press and hold brake. |
| *Note: The light is assumed to turn green at this point.* | | | |
| **7.3. Proceed Through Intersection** | | | |
| 7.3.1. Observe status of light. | Visually observe traffic signal. | Identify color/status of traffic light. | Head and eye movements to view traffic signal. |
| 7.3.2. Wait for lead vehicle to go. | Visually observe position of lead vehicle. | Identify when lead vehicle starts accelerating. | Head and eye movements to view lead vehicle. |
| 7.3.3. Make sure pedestrians/cyclists are not crossing or about to cross. | Look left and right along crosswalk. | Identify if pedestrians/cyclists are present. | Head and eye movements for viewing. |
| 7.3.4. Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | Determine if crossing vehicles are stopped or will stop in time. | Head and eye movements for observing cross traffic. |
| 7.3.5. Accelerate to get up to speed. | Visually observe roadway ahead. | Determine that acceleration is sufficient to get vehicle through the intersection in a timely manner. | Accelerate at necessary rate. |
| 7.3.6. Maintain safe distance from accelerating lead vehicle. | Visually assess distance and relative speed of lead vehicle. | Determine if lead-vehicle trajectory is safe. | Decrease acceleration if necessary.<br>Head and eye movements to view lead vehicle. |
| 7.3.7. Maintain safe lane position. | Visually observe roadway ahead. | Verify correct lane position. | Make necessary adjustments to steering. |
| 7.3.8. Check surround for unsafe situations. | Scan for potential obstacles/hazards.<br>Listen for indications of unsafe situations. | Determine whether perceptual input indicates if current situation is safe/unsafe. | Head and eye movements for scanning. |

## Segment Analysis

### *Scenario 7, Segment 1, Approach*

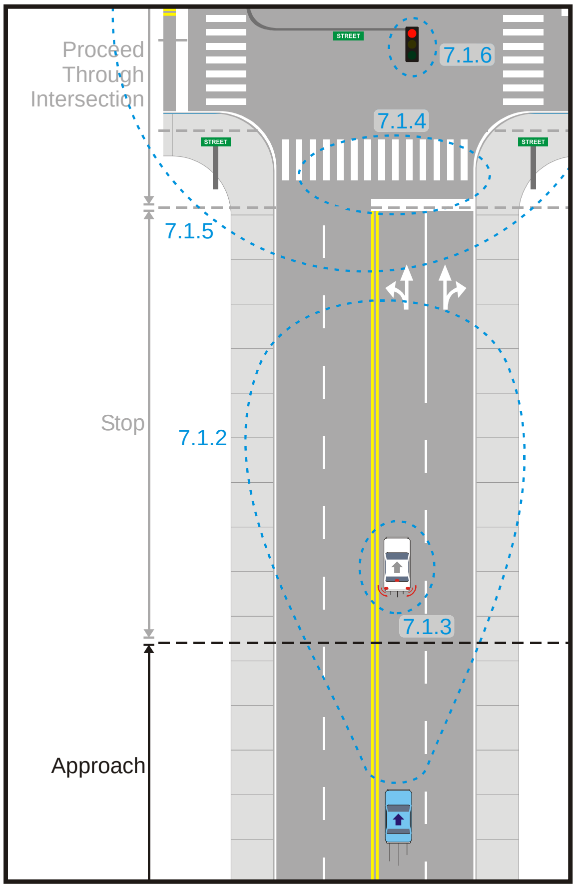
The *Approach* segment involves the subject vehicle traveling at or near full speed until the subject driver sees that the traffic light is red. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 84. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 57. Table 85 lists *Approach* segment details.

**Table 84. Scenario 7—Stop on Red Light *Approach* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 7.1.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 7.1.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 7.1.3 Maintain safe distance from lead vehicle traveling at constant speed. | Visually assess distance and relative speed of leading vehicle. | **4** | Determine if lead-vehicle trajectory is safe. | **4** | Reduce speed if necessary. Head and eye movements to view vehicle. | **3** |
| 7.1.4 Decelerate. | Visually assess distance to intersection. | **4** | Determine when vehicle is close enough to intersection to begin deceleration. | **6** | Coast (foot off accelerator) and/or gentle braking. | **3** |
| 7.1.5 Identify intersection characteristics. | Visually identify lane configurations, pavement marking and signs, signal locations. | **6** | Determine if any nonroutine actions are required. | **6** | Head and eye movements for scanning. | **1** |
| 7.1.6 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |

It is critical to note that the task 7.1.3 (*maintain safe lane position)* cognitive subtask was treated as involving the evaluation of a single dimension (workload estimate = 4), rather than as the evaluation of multiple dimensions (workload estimate = 6) based on relative speed and distance. This approach was taken because evidence suggests that drivers may evaluate time-to-arrival as a single integrated variable (*tau*) rather than as separate speed and distance components.(11) Also, the deceleration that takes place in task 7.1.4 is not the same as the deceleration in the next segment, which stops the vehicle. The task 7.1.4 deceleration is just general deceleration that should be part of any approach to an intersection.(9)

**Scenario 7, Segment 1 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 57. Scenario 7—Stop on Red Light *Approach* segment diagram.**

**Table 85. Scenario 7—Stop on Red Light *Approach* segment of relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **7.1 Approach** | **Time** *Start* → *End* |
| 7.1.1 Maintain safe lane position. | F (full duration) |
| 7.1.2 Check surround for unsafe situations. | S (full duration) |
| 7.1.3 Maintain safe distance from lead vehicles traveling at constant speed. | S (full duration) |
| 7.1.4 Decelerate. | S |
| 7.1.5 Identify intersection characteristics. | S |
| 7.1.6 Observe status of light. | ← S → |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Some perceptual tasks involving scanning in 7.1.2 and 7.1.5.
- Some cognitive tasks involving evaluation or judgment of several factors in 7.1.4 and 7.1.5.

***Mitigating factors:***

- Most of the tasks are self-paced.
- Most of the tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 3.1.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving, but the other tasks are self-paced.

Regarding the task ordering, tasks 7.1.4 through 7.1.6 are sequential and can essentially be performed in any order. The ordering chosen in this segment followed a logical sequence and was consistent with the ordering of similar tasks in the *Approach* segments in other driving scenarios included in this effort.

## *Scenario 7, Segment 2, Stop*

The *Stop* segment involves the interval from when the subject vehicle begins to decelerate, until the vehicle comes to a complete stop behind the lead vehicle. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 86. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 58 and table 87.

**Table 86. Scenario 7—Stop on Red Light *Stop* segment tasks and information processing subtasks.**

| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 7.2.1 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 7.2.2 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |
| 7.2.3 Begin deceleration. | Detect lead vehicle brake lights. | **1** | Confirm that lead vehicle is stopping. | **2** | Coast (foot off accelerator) and/or initiate braking. | **3** |
| 7.2.4 Observe vehicle stopping trajectory. | Visually assess distance to intersection. | **4** | Determine if deceleration rate will lead to safely stopping in appropriate location. | **6** | Make necessary adjustments to deceleration rate. | **3** |
| 7.2.5 Maintain safe distance from decelerating lead vehicle. | Visually assess distance and relative speed of lead vehicle. | **4** | Determine if lead-vehicle trajectory is safe.* | **5** | Increase deceleration if necessary. Head and eye movements to view lead vehicle. | **3** |
| 7.2.6 Maintain safe distance from decelerating following vehicle. | Visually assess distance and relative speed of following vehicle. | **4** | Determine if following-vehicle closing trajectory is safe.** | **5** | Reduce deceleration if necessary. Head and eye movements to observe rearview mirror. | **3** |
| 7.2.7 Observe status of light. | View overhead traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 7.2.8 Stop. | Visually assess distance to lead vehicle. | **4** | Determine when lead vehicle is in appropriate location for stopping. | **2** | Fully press and hold brake. | **2** |

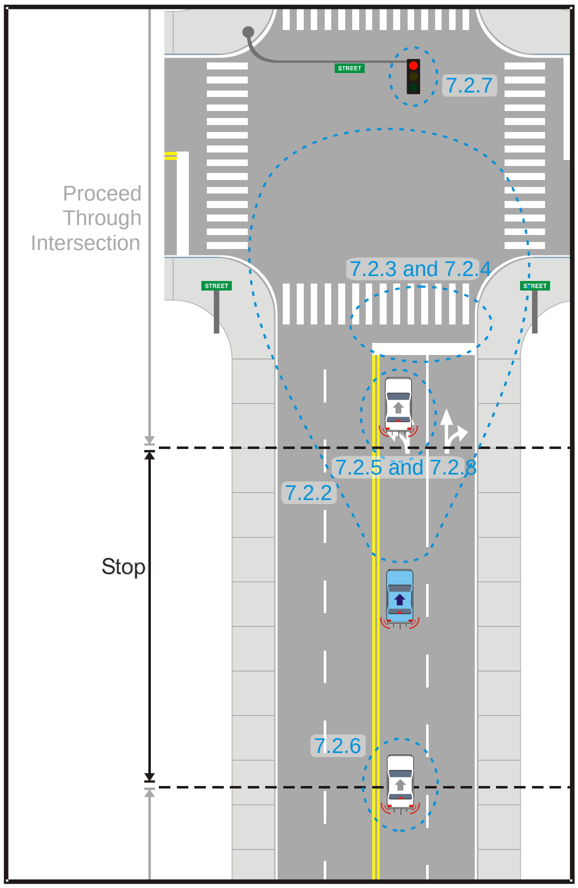
* Difficulty in this subtask is increased by a value of 1 because the lead vehicle's speed is changing.
** Difficulty in this subtask is increased by a value of 1 because of degraded information.

Several points about the task analysis and workload estimation warrant discussion. The first is that deceleration (task 7.2.3) is initiated not based on the distance to the intersection, but according to when the lead vehicle begins stopping, which forces the subject vehicle to also begin stopping. In addition, although tasks 7.2.4 (*observe vehicle stopping trajectory*) and 7.2.8 (*stop*) seem to be redundant, they have different objectives. Specifically, the purpose of task 7.2.4 is to provide global oversight to the general process of slowing and making sure that the trajectory will remain relatively smooth, whereas the purpose of task 7.2.8 is to ensure the more fine-tuned stopping and positioning of the subject vehicle behind the stopped lead vehicle.

Finally, task 7.2.8 (*observe status of light*) is included as a general check to see whether the traffic signal is still red. This task can occur at any time over the course of this segment.

Note also that this segment is made more difficult because the subject vehicle is required to maintain safe distances from lead and following vehicles. In particular, the workload value of the task 7.2.5 cognitive element was increased to reflect the increased difficulty of assessing the trajectory of the lead vehicle whose speed is changing. Also, the estimated workload value for the task 7.2.6 cognitive element was incremented by a value of 1, because determining the trajectory of the following vehicle is more difficult to do using the degraded indirect visual information from the rearview mirror.

**Scenario 7, Segment 2 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 58. Scenario 7—Stop on Red Light *Stop* segment diagram.**

**Table 87. Scenario 7—Stop on Red Light *Stop* segment of relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **7.2 Stop** | **Time** *Start* → *End* |
| 7.2.1 Maintain safe lane position. | F (start to end) |
| 7.2.2 Check surround for unsafe situations. | S (start to end) |
| 7.2.3 Begin deceleration. | F (start) |
| 7.2.4 Observe vehicle stopping trajectory. | S (middle) |
| 7.2.5 Maintain safe distance from decelerating lead vehicle. | S (start to end) |
| 7.2.6 Maintain safe distance from decelerating following vehicles. | S (start to end) |
| 7.2.7 Observe status of light. | ← S → |
| 7.2.8 Stop. | F (end) |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 7.2.1, 7.2.2, 7.2.4, 7.2.5, and 7.2.6.
- Several demanding cognitive tasks involving either evaluation or judgment of multiple simultaneous factors in 7.2.4 or a single factor under increased difficulty (7.2.5 and 7.2.6).

***Mitigating factors:***

- Most of the difficult tasks are self-paced.
- Most tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 7.2.1 (*lane maintenance*) is forced-paced because it is part of the ongoing task of driving. Task 7.2.3 (*begin decelerating*) is also forced-paced because the subject driver has to respond quickly to the lead vehicle braking. Similarly, task 7.2.8 (*stop*) is forced-paced because the subject vehicle has to stop within a certain distance behind the lead vehicle.

Regarding the task ordering, there is an obvious temporal sequence to 7.2.3 (*begin decelerating*), 7.2.4 (*observe stopping trajectory*), and 7.2.8 (*stop*), whereas the other tasks are essentially ongoing throughout the segment. The exception is task 7.2.7 (*observe status of light*), which is temporally discrete and can occur over a range of time.

***Scenario 7, Segment 3, Proceed Through Intersection***

The *Proceed Through Intersection* segment involves the subject vehicle accelerating through the intersection after the light turns green. The lead vehicle starts to move, and determines if it is safe to proceed. The tasks, information processing subtasks, and workload estimates associated with this segment are shown in table 88. The scenario diagram, relative timing of tasks, and potential contributions to information processing bottlenecks and mitigating factors are shown in figure 59 and table 89.

**Table 88. Scenario 7—Stop on Red Light *Proceed Through Intersection* segment tasks and information processing subtasks.**

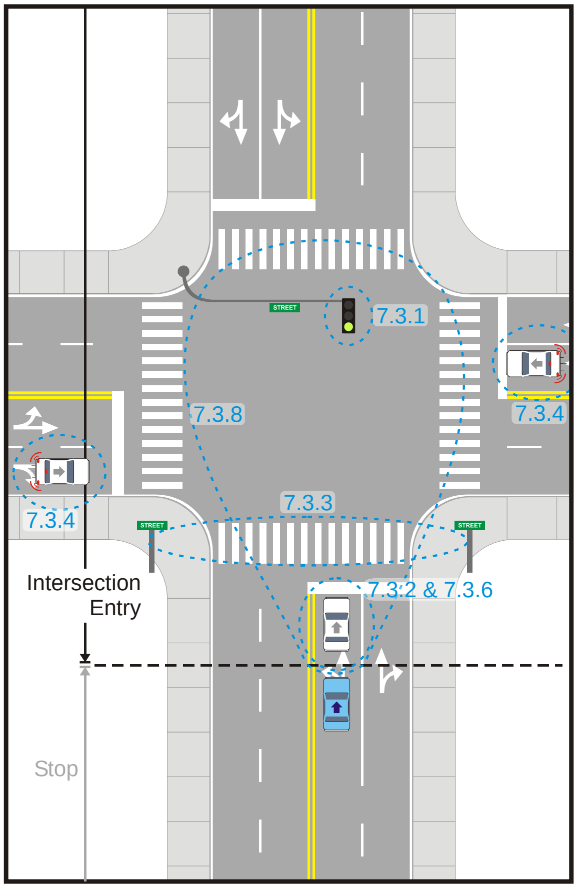
| Task | Perceptual Subtasks | | Cognitive Subtasks | | Psychomotor Subtasks | |
|---|---|---|---|---|---|---|
| 7.3.1 Observe status of light. | Visually observe traffic signal. | **2** | Identify color/status of traffic light. | **2** | Head and eye movements to view traffic signal. | **1** |
| 7.3.2 Wait for lead vehicle to go. | Visually observe position of lead vehicle. | **1** | Identify when lead vehicle starts accelerating. | **2** | Head and eye movements to view lead vehicle. | **1** |
| 7.3.3 Make sure pedestrians/ cyclists are not crossing or about to cross. | Look left and right along crosswalk. | **3** | Identify if pedestrians/ cyclists are present. | **2** | Head and eye movements for viewing. | **1** |
| 7.3.4 Check for red-light-running cross traffic. | Visually observe vehicles in left and right cross lanes. | **5** | Determine if crossing vehicles are stopped or will stop in time. | **4** | Head and eye movements for observing cross traffic. | **1** |
| 7.3.5 Accelerate to get up to speed. | Visually observe roadway ahead. | **1** | Determine that acceleration is sufficient to get vehicle through the intersection in a timely manner. | **2** | Accelerate at necessary rate. | **3** |
| 7.3.6 Maintain safe distance from accelerating lead vehicle. | Visually assess distance and relative speed of leading vehicle. | **4** | Determine if lead-vehicle trajectory is safe.* | **5** | Decrease acceleration if necessary. Head and eye movements to view lead vehicle. | **3** |
| 7.3.7 Maintain safe lane position. | Visually observe roadway ahead. | **1** | Verify correct lane position. | **1** | Make necessary adjustments to steering. | **1** |
| 7.3.8 Check surround for unsafe situations. | Scan for potential obstacles/hazards. Listen for indications of unsafe situations. | **7** | Determine whether perceptual input indicates if current situation is safe/unsafe. | **4** | Head and eye movements for scanning. | **1** |

* Difficulty in this subtask is increased by a value of 1 because the lead vehicle's speed is changing.

Tasks 7.3.3 (*make sure pedestrians/cyclists are not crossing or about to cross*) and 7.3.4 (*check for red-light-running cross traffic*) are likely to be unnecessary because the lead vehicle also has to check for these hazards before proceeding. These tasks were included to cover any unexpected hazardous actions from cross traffic or pedestrians/cyclists.

This segment is made more difficult because the subject vehicle is required to maintain safe distances from the lead vehicle. Specifically, the workload value of the task 7.3.6 cognitive subtask was increased to reflect the increased difficulty of assessing the relative speed of the lead vehicle whose speed is changing.

**Scenario 7, Segment 3 Diagram**




**Blue dotted outlines indicate general distribution of primary information in key perceptual tasks.**

Note: Illustration dimensions and vehicle positions are not to scale.

**Figure 59. Scenario 7—Stop on Red Light *Proceed Through Intersection* segment diagram.**

**Table 89 Scenario 7—Stop on Red Light *Proceed Through Intersection* segment of relative timing and duration of segment tasks and summary of key findings.**

| Task | Approximate Task Duration within Segment Timeframe |
|---|---|
| **7.3 Proceed Through Intersection** | **Time** *Start* → *End* |
| 7.3.1 Observe status of light. | S |
| 7.3.2 Wait for lead vehicle to go. | F |
| 7.3.3 Make sure pedestrians/cyclists are not crossing or about to cross. | S |
| 7.3.4 Check for red-light-running cross traffic. | S |
| 7.3.5 Accelerate to get up to speed. | S |
| 7.3.6 Maintain safe distance from accelerating lead vehicle. | S |
| 7.3.7 Maintain safe lane position. | F |
| 7.3.8 Check surround for unsafe situations. | F |

S indicates self-paced task; F indicates forced-paced task

***Potential contributions to high workload and information processing bottlenecks*:**

- Concurrent and continuous conduct of 7.3.5 through 7.3.8.

***Mitigating factors:***

- Most of the tasks are self-paced.
- Most tasks are routine, automatic activities.

*Task Pacing and Timing*—Task 7.3.2 is forced-paced because its timing is determined externally from the subject driver, but it has no practical effect on the pacing in the segment because the driver has control over when subsequent tasks are performed. The exception is task 7.3.7 (*lane maintenance*), which is forced-paced because it is part of the ongoing task of driving.

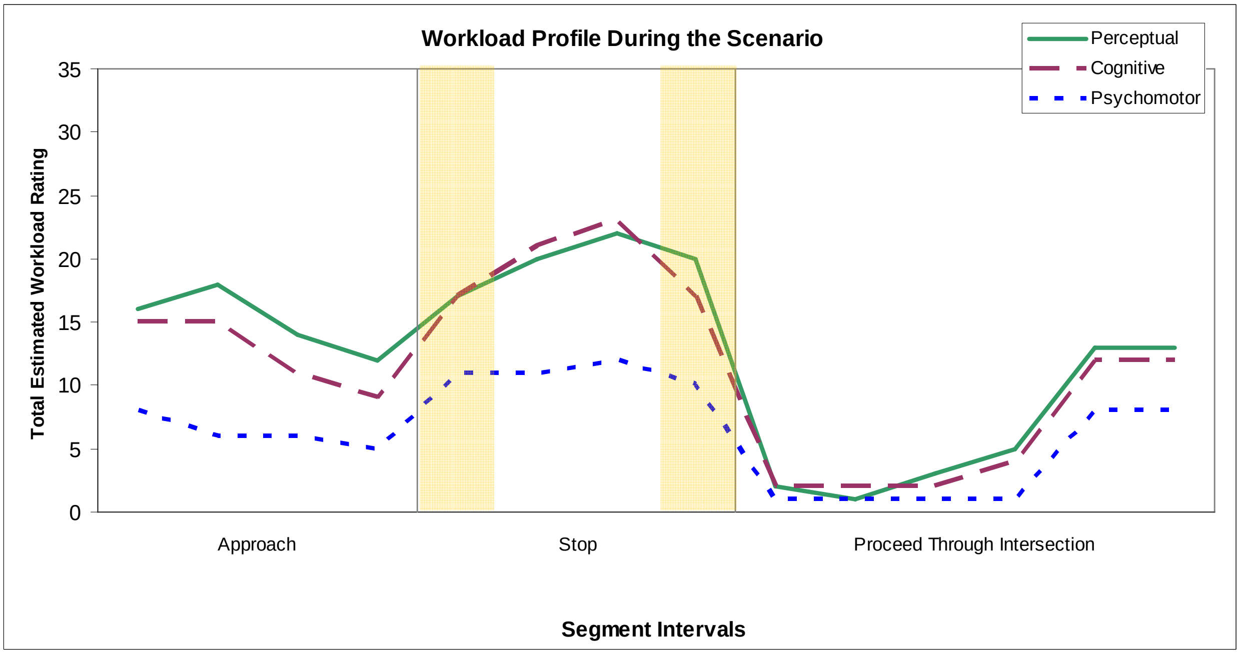
In the task ordering, the first four tasks occur sequentially in logical order, whereas the other tasks are essentially concurrent throughout the remainder of the segment.

**Scenario-Wide Analysis**

To help identify potential information processing bottlenecks in this scenario, workload estimates from all segments were combined into a single scenario-wide workload profile, which provides a general indication of where the areas of high workload demands are likely to be.

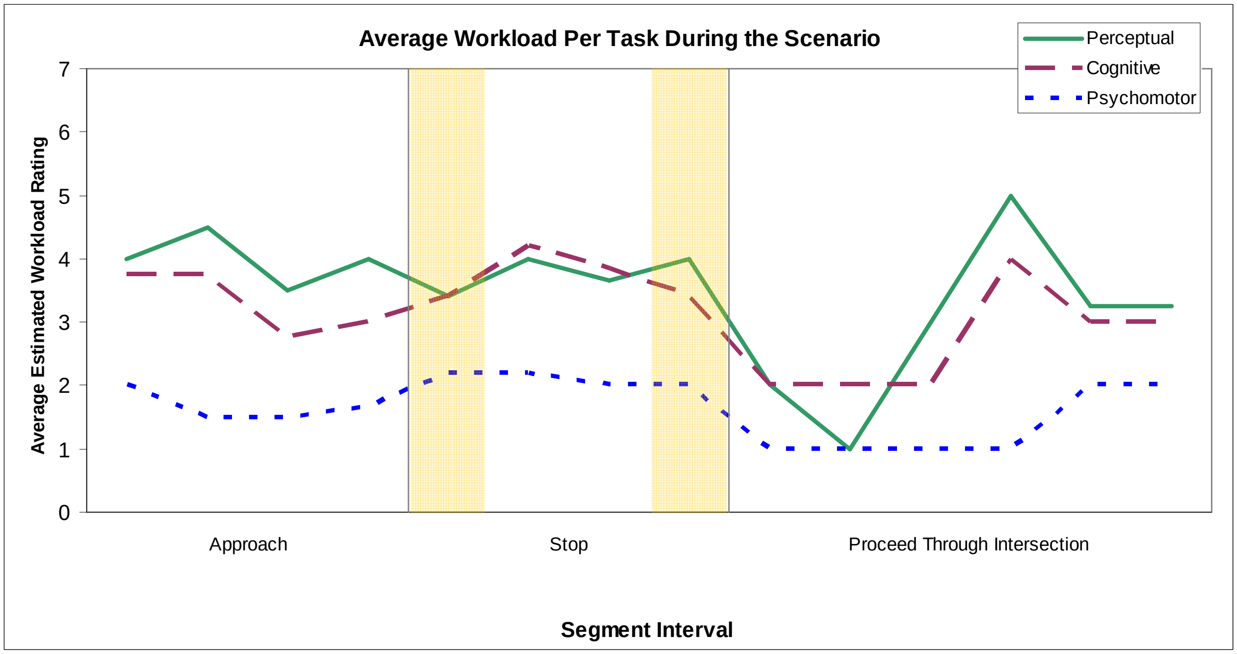
Figure 60 shows the summed workload estimates (separately for each information processing subtask) in each segment interval for the entire scenario. Also, the intervals in which key tasks are forced-paced are shaded in orange. As indicated by figure 60, the workload estimates peak for both the perceptual and cognitive elements during the *Stop* segment, with smaller peaks in the initial part of the *Approach* segment and the latter part of the *Proceed Through Intersection* segment.

Figure 61, which displays the average workload estimate of all the tasks in play during a particular segment interval, shows that the peak during the *Stop* segment in figure 60 arises largely from several tasks combined rather than just a few particularly difficult tasks. This is because the average workload values in this segment are not much greater than in the other segments. Figure 61 shows a broad peak for cognitive subtasks during the *Stop* segment, with other narrower peaks in the *Approach* and latter half of the *Proceed Through Intersection* segment. The biggest peak for the perceptual subtasks occurs during the *Proceed Through Intersection* segment; however, this peak is misleading because only a single task is being performed at that time. Otherwise, the average perceptual workload estimates indicate generally elevated levels throughout most of the *Approach* and *Stop* segments.




Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph shows the overall level of workload associated with a segment.

**Figure 60. Scenario 7—Stop on Red Light total estimated workload ratings for all tasks in each scenario segment.**




Intervals containing nonroutine forced-paced tasks are shaded in orange. This graph generally represents the overall level of difficulty associated with the tasks in a segment.

**Figure 61. Scenario 7—Stop on Red Light average estimated workload ratings per task for each scenario segment.**

### *Information Processing Bottlenecks*

Information about the combined and average workload ratings, pacing of key tasks, and nature of bottlenecks for each segment is shown in table 90. Only information that represents potential problems is listed; blank cells indicate that no substantive issues occurred for a particular segment or cell. Following the table is a list of key information processing bottlenecks identified in each of the segments.

**Table 90. Combined and average workload ratings, pacing of key tasks, and nature of bottlenecks that indicate potential problems for each scenario segment.**

| Segment | Combined Workload | Average Workload | Pacing of Key Tasks | Nature of Bottlenecks |
|---|---|---|---|---|
| *Approach* | Moderate perceptual workload. | High perceptual workload. | | Intermittent perceptual tasks that involve visual scanning or cognitive tasks that involve evaluating multiple factors. |
| *Stop* | Moderate to high perceptual and cognitive workload. | Moderate to high perceptual and cognitive workload. | Forced-pacing of some tasks. | Some concurrent tasks with moderate to high perceptual and cognitive workload. |
| *Proceed Through Intersection* | | | | Some concurrent tasks with moderate to high perceptual and cognitive workload. |

*Approach* nature of bottleneck*:* Visual demands.

- Moderate to high combined and average perceptual subtask workload involves some overlapping visual scanning tasks during the initial part of the segment. These effects are offset, however, by the self-pacing and routine, automatic nature of most of these tasks.

*Stop* nature of bottleneck: A relatively high number of concurrent tasks.

- Combined workload is high for perceptual and cognitive subtasks because several tasks are concurrent—some with either moderate to high perceptual or cognitive workload. These effects, however, are offset by the self-pacing and routine, automatic nature of most of these tasks.

# SECTION 4. SUMMARY AND CONCLUSIONS

## SUMMARY OF RESULTS

Table 91 shows a summary of the nature of the information processing bottlenecks for each scenario. This table helps identify recurring patterns among the segments, in addition to the key bottlenecks. The table's purpose was to integrate information across scenarios and segments to find consistencies on which to base more global conclusions. One caveat in interpreting table 96 is that there is redundancy within segments (columns) because many segments were comprised of the same set of core tasks with slight variations in the difficulty, number, or combination of additional tasks.

The cells in table 91 show bottleneck summaries. Scenario segments that did not have any significant bottlenecks are indicated with the text "None," and scenario and segment combinations that did not occur are indicated with the text "NA."

The following text gives a detailed summary of the key information processing bottlenecks encountered in each segment.

### *Approach* Segments Summary of Key Information Processing Bottlenecks

Generally, the difficulties associated with the *Approach* segments involve moderate visual demands arising from information acquisition requirements. These demands include some combination of tasks, which involve determining if the light is about to change, identifying intersection characteristics, and identifying an unfamiliar intersection as the turn intersection. From an information processing perspective, workload demands in some of these tasks could be reduced by making it easier for drivers to perform these tasks.

One potential problem involves the subject driver having to identify an unfamiliar intersection as the turn intersection. The key difficulty with this task relates to the limited time window for completing this task. Specifically, the street sign does not become readable until the driver is sufficiently close to the intersection, and the information must be read and recognized before the driver is too close to the intersection to decelerate safely. Although this time window in the present analysis provided a relatively long duration to perform this task (2.8 sec), for several reasons this duration may still be limiting. In particular, the visual search component of the task can be made more difficult because of inconsistent placement of signs, a complex visual environment, or placement of signs along sight lines that are not visible until the subject vehicle is relatively close to the intersection. Similarly, a variety of factors affect sign legibility, including font characteristics, distance, and illumination/reflectance. Dingus et al., list factors that may increase the time needed to read the sign.(27) The difficulty and duration of this task not only affects the driver's ability to brake safely, but, more important, it also represents time that drivers are unable to spend completing other tasks, such as scanning the roadway for potential hazards. Potential strategies for addressing this problem include increasing the conspicuity and legibility of street signs.

**Table 91. A summary of the nature of the information processing bottlenecks for each scenario.**

| | Segment | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Approach** | **Prepare for Lane Change** | **Execute Lane Change** | **Deceleration/ Stop** | **Decision to Proceed** | **Intersection Entry** | **Prepare for Turn** | **Execute Turn** |
| **1—Left on Green** | Moderate visual demands. | NA** | NA | Several concurrent tasks. | NA | None | Concurrent high workload, high-stress tasks under time pressure. | Concurrent high workload, high-stress tasks under time pressure. |
| **2—Left on Yellow** | Moderate visual demands. | NA | NA | None. | High time pressure. | High time pressure for several tasks. | NA | Concurrent tasks. |
| **3—Straight on Yellow** | Moderate visual demands. | NA | NA | NA | High time pressure. | Concurrent perceptual tasks with time pressure. | NA | NA |
| **4—Straight on Green** | None. | High time pressure. | High time pressure. | NA | NA | Distributed information. | NA | NA |
| **5—Right on Green** | Moderate visual demands. | NA | NA | Several concurrent tasks. | NA | High time pressure for several tasks. | NA | Concurrent tasks. |
| **6—Right on Red** | None. | High time pressure. | High time pressure. | A relatively high number of concurrent tasks. | NA | NA | Concurrent high workload, high-stress tasks under time pressure. | Concurrent high workload, high-stress tasks under time pressure. |
| **7—Stop on Red** | Moderate visual demands. | NA | NA | A relatively high number of concurrent tasks. | NA | None.* | NA | NA |

* This segment is "Proceed Through Intersection," but it is sufficiently similar to "Intersection Entry" to go in this column.
** NA—Not Applicable: This segment was not a part of this scenario.

### ***Prepare for Lane Change*** **and** ***Execute Lane Change*** **Segments Summary of Key Information Processing Bottlenecks**

A general problem that arises in intersection-related lane changes is that they are more likely to be time limited compared to lane changes on highways. Intersection-related lane changes are usually more time limited than lane changes on highways because the approaching intersection acts as a forced completion point. Given that a key safety aspect of lane changes is checking for potential conflicts in the destination lane (e.g., mirrors and shoulder checking), the time limitations may cause some drivers to compromise these actions. This finding is also corroborated by the crash data.(21)

Another issue that was explicitly avoided in the current task analysis but which likely complicates the lane-change maneuver relates to whether a lane change is executed in conjunction with deceleration (i.e., when the speed of lead and following vehicles in the destination lane is also changing). More specifically, the lane change would be more difficult because of the need to accommodate the changing speeds of vehicles in the destination lanes. In addition, other drivers will have higher workload demands because they are approaching the intersection, which potentially diminishes their ability to respond to the subject vehicle's lane change and any potential conflicts.

General strategies for addressing lane-change-related safety issues might involve reducing the need to make lane changes, or making the information that is used to initiate a lane change available sooner in the approach to give drivers more time to change lanes. Note that one challenge that most strategies will have to face is that lane changes may be more variable with regard to when/where they are initiated; thus, it will be necessary to accommodate vehicles that are in a range of locations along the approach.

### ***Deceleration/Stop*** **Segments Summary of Key Information Processing Bottlenecks**

The *Deceleration* and *Stop* segments were not typically associated with high workload; however, information processing bottlenecks that did occur tended to involve a high number of concurrent tasks. The key deceleration-specific tasks included decelerating at the necessary rate and maintaining appropriate spacing from other vehicles. These tasks represent ongoing activities that require repeated visual information acquisition and cognitive assessment of vehicle trajectories. In particularly complex situations with lead and following traffic, these visual and cognitive demands have the potential to interfere with drivers' ability to watch for and respond to other hazards in the roadway. Another potential problem involving decelerating and stopping relates to when the deceleration level is too low to permit gradual and safe slowing (e.g., intersections near freeway off ramps or on high-speed rural roads). Strategies for addressing these problems could focus on eliminating the conflicts between the subject vehicle and other vehicles and providing better information/cues about the subject vehicle's deceleration level.

### ***Decision to Proceed*** **Segments Summary of Key Information Processing Bottlenecks**

The key difficulty with this segment appears to be a limited duration to conduct the tasks required to decide whether or not it is safe to proceed. For example, in scenario 4, drivers had a time period of approximately 1 sec to make four different key judgments about decision-critical elements of the situation. Both the task analysis and focus group research conducted for this effort indicate that the decision to proceed is not based solely on the subject vehicle's position relative to a theoretical braking distance (although drivers must still determine this information). Instead, other information must be determined, which varies based on the complexity of the situation (e.g., presence of other vehicles). Moreover, obtaining this information involves some effort because the tasks are demanding and the required information is distributed throughout the visual environment. The task analysis shows that in complex situations, completing decision-critical tasks likely takes longer than the time available during the option zone, in which drivers still have the ability to both stop and proceed safely and legally. Strategies for addressing this problem might involve ensuring that the drivers' option zone is adequate to accommodate the necessary decisionmaking tasks. In standard calculations of the dilemma zone, the option zone is implicit in the driver's perception reaction time.(23,28) Thus, making this reaction time better reflect the complexity of different intersections in terms of configurations, traffic conditions, and other relevant characteristics may help address this issue.

### ***Intersection Entry*** Segments Summary of Key Information Processing Bottlenecks

In general, the key difficulties in the *Intersection Entry* segments are likely associated with drivers having to quickly check for potential hazards (e.g., red-light runners, oncoming vehicles turning left.) at multiple distributed locations just before they reach the intersection). This is a greater problem, however, in scenarios in which the subject driver is about to make a turn without first coming to a complete stop. In this case, there are typically additional tasks (e.g., checking for hazards in the turn path) along with less time available to perform the tasks, because the vehicle is quickly approaching the turn location. In addition, interference between these tasks is likely because they draw on the same information processing resources. Strategies for addressing these problems could focus on reducing or eliminating the need for drivers to check for some of these types of hazards by either restricting the access of the hazards to the drivers' path or by providing notification of potential hazards.

### ***Prepare for Turn*** Segments Summary of Key Information Processing Bottlenecks

The primary bottleneck in this segment is a difficult and forced-paced gap-judgment task that is complicated by having to quickly cycle among other tasks involving checking for hazards (e.g., in turn path, following vehicle) that are distributed throughout the visual environment. This is also likely to be a high-stress situation, because the consequences of making an error in the gap judgment task could be a collision with a fast-moving vehicle. Strategies for addressing these problems could focus on making the gap-judgment task easier to perform, reducing or eliminating the conflicts between the subject vehicle and other vehicles, or reducing the need for drivers to cycle their gaze among additional potential hazards.

### ***Execute Turn*** Segments Summary of Key Information Processing Bottlenecks

The initial portion of the *Execute Turn* segment, in which the subject vehicle is in the process of turning, can be associated with higher levels of workload demands. The cognitive elements of this task are particularly affected because they generally involve overseeing precise maneuvers and assessing the situation for hazards. In addition, these tasks are forced-paced because the subject vehicle is quickly accelerating and, in some cases, directly in conflict with other vehicles. This is also likely to be a high-stress situation, because the consequences of making an error in executing the turn could be a collision with a fast-moving vehicle. The strategies for addressing these problems would likely be similar to those in the *Prepare for Turn* segments.

## GENERAL CONCLUSIONS ON THE NATURE OF THE BOTTLENECKS

At a basic level, the current analysis shows that information processing bottlenecks are likely to occur in specific situations during intersection driving. In addition, there appears to be a relatively high degree of consistency regarding the nature of bottlenecks across segments and scenarios. More specifically, time constraints and forced-pacing of tasks seem to be recurrent issues regarding information processing bottlenecks. The general problem seems to be that there is a limited amount of time available to perform a variety of different yet necessary tasks. Also, many of these tasks draw on the same perceptual and cognitive resources, which leads to more time-consuming sequential execution and also increases the potential for “interference” between tasks. This consistency related to the underlying causes of information processing bottlenecks makes it possible to apply this task analysis approach to identify potential safety issues.

Another general conclusion about bottlenecks is that in many cases it appears to be possible to develop strategies that specifically address the underlying information processing limitations associated with specific types of bottlenecks. For example, the current task analysis identified high visual/perceptual demands as a source of potential information processing bottlenecks during several of the *Approach* segments. The specific problems identified, including high information acquisition loads and time pressure in some instances, directly lead to strategies for addressing related problems (e.g., making those information acquisition tasks easier and quicker to perform). Thus, by gaining a more complete understanding of the underlying information processing aspects of potential problems, it is possible to identify general strategies that can directly address key underlying challenges associated with specific intersection driving situations.

## ADVANTAGES OF THE TASK ANALYSIS APPROACH

The key advantage of the task analysis approach taken in this effort is that it provides unique information and perspective on intersection driving. In particular, this task analysis provides a useful complement to existing approaches for investigating driving behavior, such as crash data analyses, performance studies, focus group research, and even more traditional task analysis approaches. Set out below is a brief summary of some limitations of these approaches compared to the present task analysis approach:

- *Crash data analyses*. These are focused on outcomes and provide limited information or understanding about driver actions or activities that lead to crashes.
- *Performance studies.* These provide important information about driver activities and tasks, especially their dynamic aspects; however, they typically focus on a small range of driving situations and lack a common framework for synthesizing information across driving situations.

- *Focus group research.* This approach is good for getting information about driver attitudes, beliefs, motivations, and the like, in various driving situations and it also useful for obtaining a global sense of what various driving situations entail. Focus groups are not good for getting specific information about driving tasks, however, and the information generated varies in detail, and often in quality, across situations.
- *Traditional task analyses.* This method provides the same systematic approach to identifying driving tasks in different scenarios but it generally lacks the additional knowledge about the information processing aspects and scenario dynamics that is key to identifying potential bottlenecks.

The limitations discussed for the previous approaches demonstrate that the current approach provides valuable information not generally available through typical driving safety research approaches.

Another key advantage is that this current approach is well suited for providing information about the potential effectiveness of safety countermeasures. As shown in the previous discussion of the nature of segment-specific bottlenecks, this approach provides specific information about the underlying information processing elements associated with the bottlenecks that can occur in specific driving situations. Thus, this information can point to general strategies for addressing these potential bottlenecks and, more importantly, provide a basis for identifying countermeasures that may be well suited to addressing specific types of safety problems.

In addition to the advantages discussed previously, another benefit of the current approach is that it allows converging evidence to be used to identify potential bottlenecks. In particular, this approach employs indicators of overall workload, time constraints/scenario dynamics, identification of conflicting tasks (that draw on the same resources), and general distribution of information sources. These converging information sources allow researchers to attach some level of confidence to their conclusions about potential bottlenecks, in addition to providing a more complete understanding about the underlying nature of these problems.

Finally, the current task analysis approach is a relatively low-cost way to get this information. In this particular instance, existing task analysis research was used to populate the scenario task lists. In addition, the dynamics of the scenarios were estimated computationally using vehicle kinematics and prespecified assumptions about each scenario. All of these were analytical activities that could be conducted without requiring expensive data collection.

## FUTURE RESEARCH

There are several directions for future research involving the task analysis approach used in this research effort. The most obvious future research direction is to apply this approach to additional intersection or roadway configurations. This task analysis can be applied to most driving situations that take at least a few seconds to navigate and that involve sequences of actions that contain some degree of complexity. Following is a list of some examples:

- Stop controlled and uncontrolled intersections.
- Intersections with different configurations such as T-junctions and lane channelization.

- Other roadway features such as roundabouts and complex multi-exit freeway exits.

One consideration when applying the current approach to other scenarios is the availability of crash data for potential scenarios, which would be useful for identifying candidate analysis situations and also for identifying specific scenario details—particularly if data exist on driver-related causal factors. Overall, these applications would provide the same type of information as the current analysis, which primarily includes information about potential information processing bottlenecks and insight into strategies for addressing the corresponding safety issues.

In addition to new scenario types, it is also possible to examine variations in existing scenarios to gain an understanding of how the task composition and overall scenario dynamics might be different in other situations. This examination would likely involve changes to key assumptions (e.g., travel speeds, sight/reading distances), which would in turn affect what tasks should be included and when they could occur. Possible variations could include some of the following examples:

- Capacity-limited drivers such as older drivers.
- Adverse weather conditions.
- Intersections with different speed profiles such as rural intersections.
- Intersections with different types of visibility issues such as street parking that might have sight obstructions caused by large vehicles, sight triangle obstructions such as trees, or intersections on grades.

Conducting task analyses on these variations could provide converging support for identified bottlenecks. In addition, this process could find situations that may not have been identified as particularly problematic in the current task analysis but could potentially become bottlenecks under less favorable conditions.

Another application may be the analysis of individual intersections, such as new or redesigned intersections that are in the planning stages. Using the task analysis in this way could provide some initial indication of potential safety issues in absence of crash histories or other operational data. One advantage of using the task analysis on a single intersection is that more detail could be incorporated into the assumptions (e.g., actual sight triangles, specifications of intersection configuration and elements), which would provide more precise timing and dynamics information, in addition to providing better guidance for the allocation of tasks within scenarios. With more development, the process of conducting a task analysis eventually could be automated or established with procedures to make the task analysis more cost effective.

Finally, another important area of future research could involve conducting empirical research to help validate the allocation of tasks within individual scenarios. For example, focus group research could be conducted to determine the extent to which drivers concur with the task lists and sequences, identify the location of bottlenecks, and identify which tasks drivers are more likely to skip when time is limited. Another important source of empirical validation could come from examining data from naturalistic driving studies, such as the 100-car study at Virginia Tech Transportation Institute.[(29)] These data could provide important information about the allocation and sequencing of observable tasks as well as the temporal dynamics of driver behavior.

Questions about some assumptions made in the current task analysis could also be refined based on data from in-vehicle studies. For example, data are lacking on how far away from the intersection drivers begin making lane changes, and how much time and distance they take to complete the lane change. In general, empirical research could provide important guidance about overall driver strategies for navigating different driving situations as well as provide information about when and how frequently drivers perform certain key tasks.

# APPENDIX A. SCENARIO TIMING AND KINEMATICS

This appendix provides details about how the scenario timing information and milestones used to make decisions about task allocation and timing were derived. More specifically, each scenario has an approximate timeline showing the key temporal milestones that represent key events that can be pinpointed in time based on scenario dynamics and assumptions. These milestones were used to make judgments about the pacing of tasks within scenario segments (e.g., forced-paced versus self-paced), as well as to provide a basis for the overall sequencing of certain sets of tasks. Where possible, milestones were calculated based on vehicle kinematics. This appendix provides details about the underlying equations, variables, results, and assumptions used to calculate timing values for each milestone. The resulting milestones were then incorporated into scenario timelines to provide an overview of the general timing of the scenario events.

Note that the timelines are not based on the absolute timing of events. They could not be done on this basis because most scenarios contained segments with undetermined durations (e.g., waiting for a safe gap in traffic), which make a time zero reference point impossible to determine. Consequently, the timeline is limited to showing the time interval between successive milestones or the duration of key tasks. The intervals between milestones that are presented in the timelines are always shown in bold in the milestone calculation tables. Also note that the timelines differentiate between normal driving-related milestones and hazard-related milestones (pictured in red). The hazard milestones provide information about approximately when the subject driver should have completed tasks associated with checking for specific hazards. Although these hazard milestones may be temporally interspersed with the other milestones, they are presented separately at the end of each set of scenario milestone descriptions. Moreover, they are displayed in the timelines without reference to other landmarks, with the implicit assumption that they represent some fixed time duration before the hazard (e.g., red-light-running vehicle) would be encountered in the roadway.

The kinematic features of each scenario, which determined the temporal and physical placement of the milestones, included acceleration and deceleration levels, RT, sight distances to the intersection, vehicle gap distances, and braking distances. The scenario dynamics and any associated assumptions were based on established values and guidelines described in the human factors literature and standard roadway design reference materials, such as the AASHTO Green Book[3] and the MUTCD.[4] Also, distances traveled and times of travel were calculated using standard motion equations found in any general physics text. (See Halliday, Resnick, and Walker,[5] page 20, to obtain these equations.)

## GENERAL ASSUMPTIONS

To determine the key temporal milestones associated with the scenario events, several assumptions were made regarding roadway geometry and design, RT, acceleration/deceleration levels, vehicle dimensions, and other elements in each of the scenarios. Table 92 lists the most commonly applied assumptions for determining the vehicle kinematics along with references to the information sources that provide a justification for the assumptions. These general assumptions apply to all milestones in the scenarios except in special cases; deviations from these assumed values are noted in the discussions of the scenario milestone calculations. Note that Green Book references refer to the 2004 AASHTO edition.[3]

Another general assumption that applies to the *Approach* segments of all scenarios is that although the scenario task analyses all specify that the subject vehicle decelerates slightly at the start of the *Approach* segment, it is assumed that the subject vehicle is traveling faster than 50 km/h at the start of the segment and that this initial deceleration reduces travel speed to a constant 50 km/h.

**Table 92. Commonly applied assumptions with corresponding justification.**

| Assumption | Value | Reference |
|---|---|---|
| Motor reaction time (used for braking and accelerating and other tasks under normal conditions). | 0.4 sec | Green 2000 †[30] |
| Perceptual-motor reaction time for emergency/evasive actions. | 0.70 sec | Green 2000 ††[30] |
| Roadway design speed. | 50 km/h | Green Book, p. 7[3] |
| Vehicle length. | 5.8 m | Green Book, p. 16[3] |
| Vehicle minimum centerline turn radius. | 6.4 m | Green Book, p. 19[3] |
| Comfortable deceleration level. | −3.4 meters per second squared (m/sec$^2$) | Green Book, p. 111[3] |
| Hard (emergency) deceleration level. | −4.5 m/sec$^2$ | Green Book, p. 111[3] |
| Acceleration level. | 2.0 m/sec$^2$ | Akçelik and Besley (2002) †††[31] |

† Many calculations involving a driver response used a motor response time instead of a perceptual-motor response time. The reason for this was that the perceptual, cognitive, and decisionmaking components of these activities are already represented in the task analysis, and including them in the RT would artificially reduce the time available for conducting those tasks. Also, the value of 0.4 sec for the motor RT was selected—even though it is on the upper end of the range of observed motor times[30] because it better generalizes both the time-critical and more leisurely situations in which the motor RT is applied in this analysis. At a practical level, however, the short time difference between the 0.4 sec motor RT and the observed lower bound of 0.2 sec for motor RTs would have negligible effect on the time available to conduct scenario tasks.

†† Calculations involving emergency or evasive maneuvers used a 0.70 perceptual-motor RT. This represents a best-case average RT for an expected event.[30] In this case, an expected event is assumed rather than an unexpected event, because if the drivers are performing the tasks listed in the task analysis, the subject driver should be led to expect the hazard in most instances. Note that in contrast to elsewhere in this analysis—where just a motor RT is used—this RT represents both motor and perceptual components of the response. Both components were combined because detecting and reacting to a hazard in this manner seems to be an automatic or self-contained action (Groeger, 2000).[11]

††† To simplify the calculations, we used a constant acceleration level interpolated from acceleration tables and models.[3,31] The value that we used (2.0 m/sec$^2$) ended up being on the high end of the interpolation, but this was necessary because lower values did not provide sufficient clearance when the subject vehicle was accelerating through gaps in oncoming traffic.

## SCENARIO KINEMATICS

The following sections describe the calculations used to determine the key temporal milestones based on vehicle kinematics for each scenario. Each description contains the following elements:

- A timeline summarizing the timing of the milestones in relation to the scenario segments. The timeline is based on the results of the milestone calculations presented in this appendix.
- A table of key temporal milestones.
- A description of each milestone.
    - A textual description of the milestone.
    - A table listing the equations used to calculate the timing and distances associated with the milestone and the assumptions made for the calculation.
    - Additional information regarding assumptions where applicable.

Note that the units used in all equations conform to the International System of Units (SI) meter-second-kilogram (MSK) standard. Therefore, distance is calculated in m, speed is calculated in meters per second (m/sec), acceleration is calculated in m/sec$^2$, and time is calculated in sec. For the convenience of the reader, some variables discussed in the assumptions are described in other units (e.g., speeds measured in km/h); however, the calculations were made using MSK units.

## SCENARIO 1—LEFT TURN ON GREEN LIGHT

Figure 62 provides the timeline and calculated vehicle speed information for scenario 1. The key temporal milestones are described in table 93. Some milestones that are shown in figure 62 (e.g., intersection becomes visible) are not described in table 93 and do not have corresponding timestamps computed. These milestones either do not affect the scenario timing in a meaningful way, or they cannot be computed because of insufficient information. They are included only to provide additional contextual information for understanding the timeline.

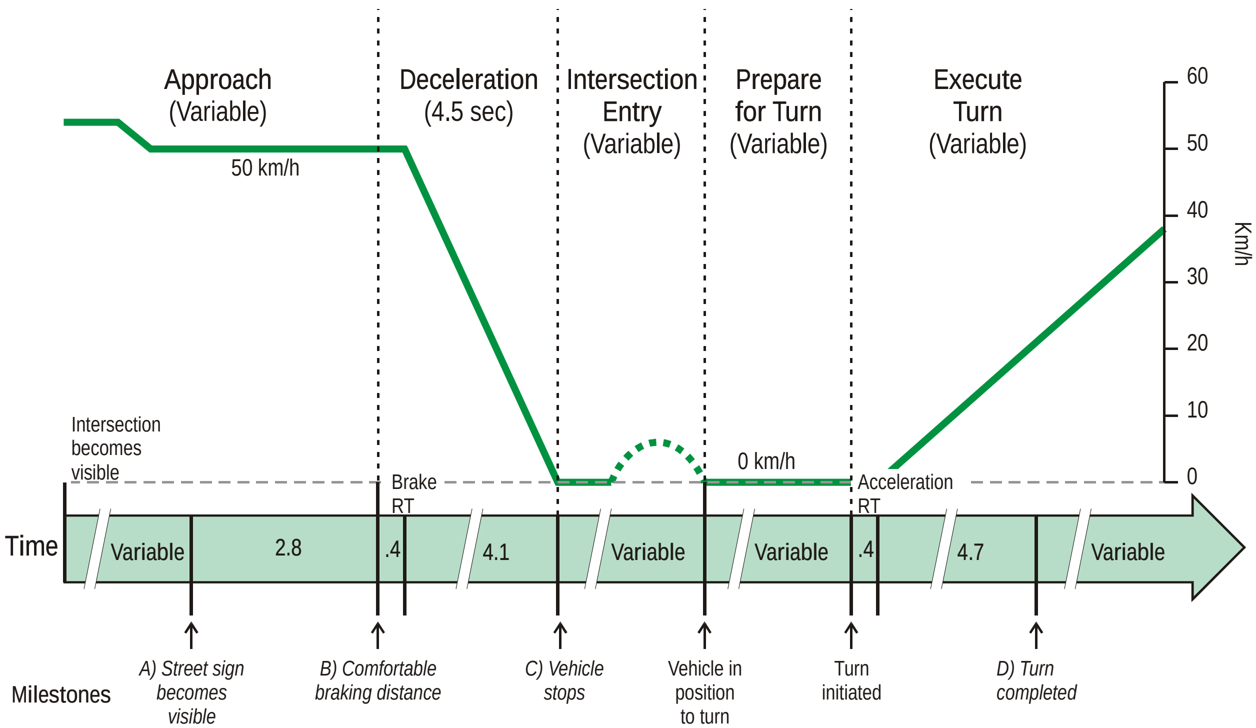



**Figure 62. Scenario 1—Left Turn on Green Light timeline depicting key temporal milestones.**

**Table 93. Scenario 1—Left Turn on Green Light description of key temporal milestones.**

| Key Milestones | | Description |
|---|---|---|
| A | Street sign becomes readable. | This milestone provides the earliest point at which the driver can begin determining if the intersection is the correct turn intersection (task 1.1.7) and, in conjunction with the braking distance (next milestone), indicates the time available to perform tasks 1.1.7 and 1.1.8. |
| B | Comfortable braking distance. | This milestone provides the latest point at which the driver can begin decelerating and maintain a comfortable deceleration level. It also represents the time point before which the driver should have completed tasks 1.1.7 and 1.1.8. |
| C | Vehicle stops. | This milestone is the point where the vehicle comes to a complete stop at the stop line and marks the endpoint of segment 2 (*Deceleration*). |
| D | Turn completed. | This milestone represents the end of the interval in which the subject vehicle is actively engaged in turning (tasks 1.5.1 through 1.5.3) and is directly in the path of oncoming traffic (after the *acceleration RT*). |

### Milestone A—Street sign becomes readable

This milestone provides the earliest point at which the driver can begin reading the street signs to determine if the intersection is the correct turn intersection (task 1.1.7). It also indicates the time available to perform tasks 1.1.7 and 1.1.8 in conjunction with the braking distance (next milestone). Table 94 lists the equations and assumptions in Scenario 1—Left Turn on Green Light, Milestone A.

**Table 94. Scenario 1—Left Turn on Green Light equations and assumptions for Milestone A.**

| Description | Equations | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Distance from intersection that street sign becomes readable. | $d_{read} = 0.48\,\text{m} \times \text{height of text in mm}$ | 1 | 73 m | • Street sign letter height of 152.4 millimeters (mm).† <br> • Typical symbol reading distance of 12.2 m/(25.4 mm of text height).†† |
| Distance traveled to braking distance. | $d_{cutoff} = d_{read} - d_{decel}$ | 2 | 39 m | • $d_{decel}$ taken from Milestone B <br> • Vehicle is traveling at a constant speed of 50 km/h. |
| **Time available to read the sign.** | $t_{sign} = \frac{d_{cutoff}}{v_0}$ | 3 | 2.8 sec | • Vehicle is traveling at a constant speed of 50 km/h. |

†MUTCD reference for letter height: p. 2D-17.(4)
††MUTCD reference for sign distance relative to letter height: p. 2A-7. (4)

### Milestone B—Comfortable braking distance

Milestone B provides the latest point at which the driver can begin decelerating and maintain a comfortable (nonemergency) deceleration level until coming to a full stop at the stop line. It also represents the time point before which the driver should have completed tasks 1.1.7 and 1.1.8. Table 95 lists equations and assumptions for Scenario 1—Left Turn on Green Light, Milestone B.

**Table 95. Scenario 1—Left Turn on Green Light, Milestone B, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Braking reaction time ($t_{BRT}$).** | *Assumed value* | – | 0.4 sec | • General motor RT. |
| **Deceleration interval (excludes braking RT).** | $t_{decel} = -\frac{v_0}{a}$ | 4 | 4.1 sec | • Vehicle traveling at 50 km/h at onset of braking ($v_0$). • Vehicle decelerates at a constant level of −3.4 m/sec$^2$ ($a$). |
| Distance traveled during deceleration (includes braking RT). | $d_{decel} = 0.5at_{decel}^2 + v_0(t_{decel} + t_{BRT})$ | 5 | 34 m | • Vehicle traveling at 50 km/h at onset of braking ($v_0$). • Vehicle decelerates at a constant level of −3.4 m/sec$^2$ ($a$). |

### Milestone C—Vehicle stops

This is the point where the vehicle comes to a complete stop at the stop line and marks the endpoint of segment 2 (*Deceleration*). Table 96 lists equations and assumptions for Scenario 1—Left Turn on Green Light, Milestone C.

**Table 96. Scenario 1—Left Turn on Green Light, Milestone C, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Time to stop line once decision is made to stop.** | $t_{stop} = t_{BRT} + t_{decel}$ | 6 | 4.5 sec | • Vehicle comes to a complete stop at the stop line. • $t_{BRT}$ (0.4 s) and $t_{decel}$ (4.1 sec) taken from Milestone B. |

### Milestone D—Turn completed

Milestone D represents the interval from the onset of the turn (including the motor RT) up until the turn is complete (tasks 1.5.1 through 1.5.3), and it represents the time that the subject vehicle is directly in the path of oncoming traffic (after the acceleration motor RT). Table 97 lists equations and assumptions for Scenario 1—Left Turn on Green Light, Milestone D.

**Table 97. Scenario 1—Left Turn on Green Light, Milestone D, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Acceleration reaction time ($t_{ART}$).** | *Assumed value* | – | 0.4 sec | • General motor RT.† |
| **Time to complete turn.** | $t_{turn} = \sqrt{\frac{2d_{turn}}{a}} + t_{ART}$ | 7 | 4.7 sec | • Distance from turn location to completion point is 22 m($d_{turn}$) including vehicle length. • Vehicle accelerates at a constant level of 2.0 m/sec$^2$ ($a$). |

†The cognitive/perceptual elements of this action are defined as being part of the preceding tasks. More specifically, the decision to turn is the culmination of tasks 2.4.5 through 2.4.8 of the preceding segment; thus, this RT simply represents the time needed to press the accelerator and start turning the steering wheel following this decision.

## SCENARIO 2—LEFT TURN ON YELLOW LIGHT

Figure 63 provides the timeline and calculated vehicle speed information for scenario 2. The key temporal milestones are described in table 98. Some milestones shown in figure 63 (e.g., intersection becomes visible) are not described in table 98 and do not have corresponding timestamps computed. These milestones either do not affect the scenario timing in a meaningful way, or they cannot be computed because of insufficient information. They are included only to provide additional contextual information for understanding the timeline.

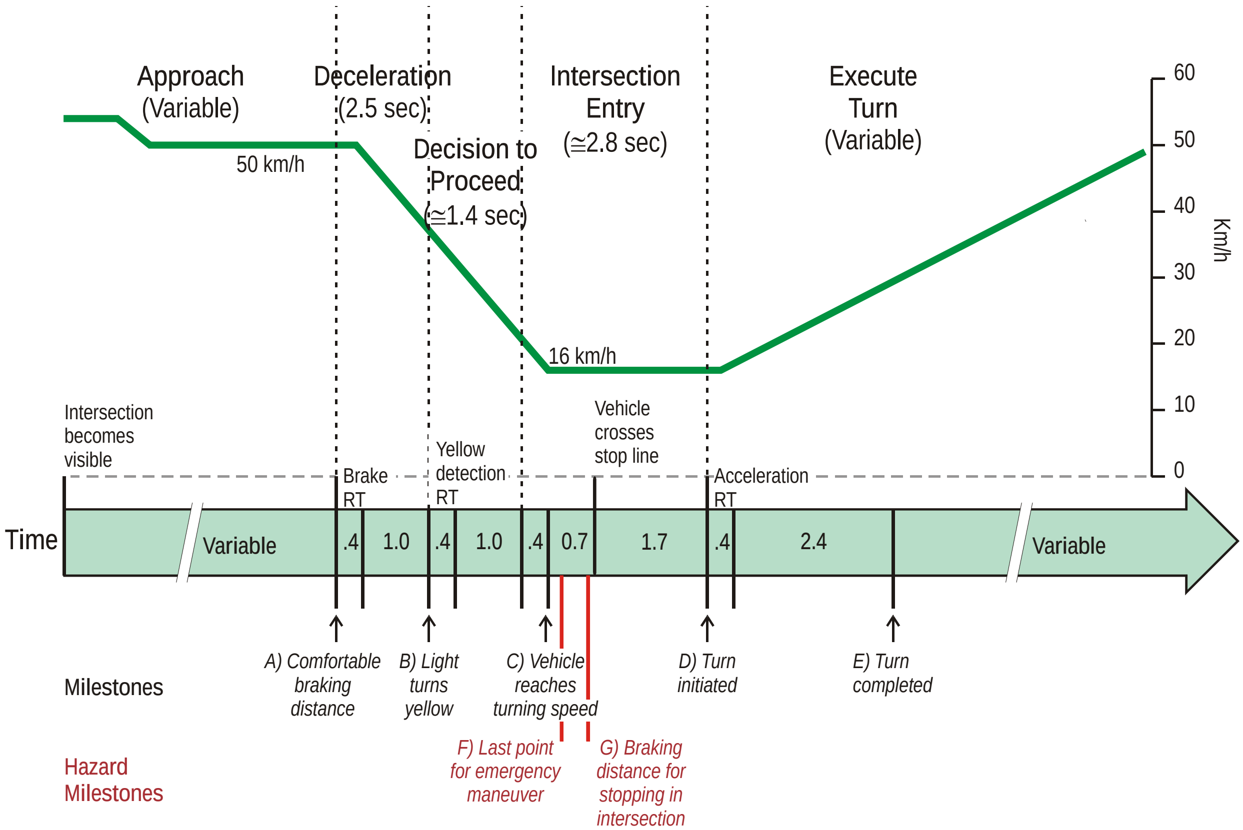



**Figure 63. Scenario 2—Left Turn on Yellow Light timeline depicting key temporal milestones.**

**Table 98. Scenario 2—Left Turn on Yellow Light description of key temporal milestones.**

| Key Milestones | | Description |
|---|---|---|
| A | Comfortable braking distance. | Provides the latest point at which the driver can begin decelerating and maintain a comfortable deceleration level. It also specifies the endpoint of the *Approach* segment. |
| B | Traffic signal turns yellow. | Marks the beginning of segment 3 (Decision to Proceed) and determines how much time the driver has to complete the following segments (3 through 5). |
| C | Vehicle reaches turning speed. | The point at which the subject vehicle reaches the turning speed and then continues towards the turn location at a constant speed. |
| D | Initiate turn. | The point at which the subject vehicle arrives at the location where it is necessary to begin the left turn. It also marks the end of the *Intersection Entry* segment. |
| E | Turn completed. | Represents the interval in which the subject vehicle is actively engaged in turning (tasks 2.5.1 through 2.5.3). |
| **Hazard Milestones** | | **Description** |
| F | Braking distance for stopping in the intersection. | This is the last point in time that the subject vehicle can still come to a stop in the intersection before starting the turn trajectory. It represents the point by which the driver must have determined that it is safe to proceed (e.g., there are no oncoming vehicles–task 2.4.6–or hazards in the turn path–task 2.4.7). |
| G | Last point for emergency maneuver in reaction to red-light runners. | This represents the latest time by which the subject driver can detect and respond to the hazard in order to initiate at least a minimal evasive action (task 2.5.3). |

### Milestone A—Comfortable braking distance

Milestone A is the latest point at which the driver can begin decelerating and maintain a comfortable deceleration level. It also specifies the endpoint of the *Approach* segment. Table 99 lists the equations and assumptions for Scenario 2—Left Turn on Yellow Light, Milestone A.

**Table 99. Scenario 2—Left Turn on Yellow Light, Milestone A, equations and assumptions.**

| Description | Equation | Eq. | Result | Assumptions |
|---|---|---|---|---|
| **Braking reaction time ($t_{BRT}$).** | *Assumed value* | – | 0.4 sec | • General motor RT |
| **Deceleration interval (excludes braking RT).** | $t_{decel} = -\frac{v_0}{a}$ | 8 | 4.1 sec | • Vehicle traveling at 50 km/h at onset of braking (v0).<br>• Vehicle decelerates at a constant level of−3.4 m/sec$^2$(a).<br>• Projected deceleration endpoint (0 km/sec) is the stop line.† |
| Deceleration distance (excludes braking RT). | $d_{decel} = 0.5at_{decel}^2 + v_0 t_{decel}$ | 9 | 28 m | • Vehicle traveling at 50 km/h at onset of braking (v0).<br>• Vehicle decelerates at a constant level of −3.4 m/sec$^2$ (a). |

†An endpoint of 0 km/h at the stop line was used to calculate the starting point for braking, with the assumption that the vehicle continues at a constant speed after reaching 16 km/h. This endpoint was selected instead of the turn location because it is more conservative (drivers can stop more easily for hazards at the crosswalk). At a practical level, however, the difference between this endpoint and an endpoint of 16 km/h at the turn location is negligible.

### Milestone B—Traffic signal turns yellow

This milestone marks the beginning of *Decision to Proceed, segment 3,* and it determines how much time the driver has to complete the following segments 3 through 5 (table 100). One point to note is that the yellow light onset time is arbitrary, but nevertheless important, because it affects the allocation of tasks within segments and the time available to perform some of those tasks. A primary objective in setting the yellow onset time was to have the light change when it was not safe for the subject vehicle to stop (which works out to be just after the braking distance in this scenario). Another consideration was that the light should not change to red until after the turn was initiated (start of *Execute Turn* segment), so that the subject driver would still be required to check for—and need to able to stop in response to—oncoming traffic crossing on a late yellow light. Thus, a yellow onset time of 2.5 sec after the start of the *Deceleration* segment (and exactly 4 sec before the *Execute Turn* segment) was chosen because it maximizes the time available to perform the tasks that need to be completed before the start of the *Execute Turn* segment, while still meeting the other requirements.

**Table 100. Scenario 2—Left Turn on Yellow Light, Milestone B, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Yellow light detection time ($t_{DRT}$).** | *Assumed value* | – | 0.4 sec | • Light detection time.† |
| **Time to make decision to proceed.** | *Assumed value* | – | 1.0 sec | • Arbitrary time interval representing the time required to make decision to proceed. |
| **Yellow phase duration.** | *Assumed value* | – | 4.0 sec | • Yellow light duration time of 4 sec.†† |

†The detection time is based on the perception RT reported in studies in which drivers respond to a light-based event, such as the change in traffic light or the onset of brake lights. The value chosen (0.4 sec) is on the high end of observed values reported in Green (2000).[30]

††A yellow phase duration of 4 sec represents the upper bound of recommended phase durations.[23] This value was chosen in order to remain consistent with the yellow phase duration used in scenario 3 (see the *Segment 3* timeline discussion above for an explanation of the basis of this assumption). An advantage of using this interval duration was that it allowed the yellow onset to occur relatively far back in the intersection, which permitted the use of a more complicated scenario because the subject driver would still have time to complete a larger set of tasks before turning.

### Milestone C—Vehicle reaches turning speed

Milestone C represents the point at which the subject vehicle reaches the turning speed and then continues toward the turn location at a constant speed. Table 101 lists equations and assumptions for Scenario 2—Left Turn on Yellow Light, Milestone C.

**Table 101. Scenario 2—Left Turn on Yellow Light, Milestone C, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Time required to decelerate to turning speed ($t_{tv}$).** | $t_{tv} = \frac{v_f - v_0}{a}$ | 10 | 2.8 sec | • Vehicle decelerates at a constant level of −3.4 m/sec$^2$ (*a*) from 50 km/h ($v_0$) to 16 km/h ($v_f$). |
| Distance traveled until turn speed reached. | $d_{tv} = 0.5at_{tv}^2 + v_0 t_{tv}$ | 11 | 25 m | |

### Milestone D—Initiate turn

Milestone D represents the point at which the subject vehicle arrives at the location where it is necessary to begin the left turn. It also marks the end of the *Intersection Entry* segment. Table 102 lists equations and assumptions for Scenario 2—Left Turn on Yellow Light, Milestone D.

**Table 102. Scenario 2—Left Turn on Yellow Light, Milestone D, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Time required to travel from point at which turning speed reached until stop line reached.** | $t_{stopline} = \frac{d_{decel} - d_{tv}}{v}$ | 12 | 0.7 sec | • $d_{decel}$ (28 m) from Milestone A.<br>• $d_{tv}$ (25 m) from Milestone C.<br>• Vehicle traveling at constant speed of 16 km/h ($v$). |
| Distance to turn point from stop line ($d_{TP}$). | *Assumed value* | – | 7.6 m | • Value determined from roadway geometry. |
| **Time required to travel from stop line to turn point at constant speed.** | $t_{TP} = \frac{d_{TP}}{v}$ | 13 | 1.7 sec | • Vehicle traveling at constant speed of 16 km/h ($v$). |

## Milestone E—Turn completed

Milestone E represents the interval in which the subject vehicle is actively engaged in turning (tasks 2.5.1 through 2.5.3). Table 103 lists equations and assumptions for Scenario 2—Left Turn on Yellow Light, Milestone E.

**Table 103. Scenario 2—Left Turn on Yellow Light, Milestone E, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Acceleration/steering reaction time ($t_{ART}$).** | *Assumed value* | – | 0.4 sec | • General motor RT.† |
| Distance traveled during motor reaction time. | $d_{ART} = v_0 t_{ART}$ | 14 | 1.8 m | • Vehicle traveling at constant speed of 16 km/h (v0). |
| Distance through turn. | $d_{turn} = d_{path} - d_{ART}$ | 15 | 16.7 m | • Total path distance through the intersection of 18.5 m including vehicle length ($d_{path}$). |
| **Time required to accelerate through turn.** | $t_{turn} = \frac{-v_0 + \sqrt{v_0^2 + 2ad_{turn}}}{a}$ | 16 | 2.4 sec | • Vehicle accelerates at a constant level of 2.0 m/sec$^2$ ($a$). |

†The cognitive/perceptual elements of this action are defined as being part of the preceding tasks. More specifically, the decision to turn is the culmination of tasks 2.4.5 through 2.4.8 of the *Intersection Entry Segment*. Thus, this RT simply represents the time needed to press the accelerator and start turning the steering wheel following this decision.

### Milestone F—Braking distance for stopping in the intersection

Milestone F is the last point in time that the subject vehicle can still come to a stop in the intersection before starting the turn trajectory. It represents the point by which the driver must have determined that it is safe to proceed (e.g., there are no oncoming vehicles–task 2.4.6–or hazards in the turn path–task 2.4.7). Table 104 lists equations and assumptions for Scenario 2—Left Turn on Yellow Light, Milestone F.

**Table 104. Scenario 2—Left Turn on Yellow Light, Milestone F, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Emergency perceptual-motor reaction time ($t_{ERT}$). | *Assumed value* | – | 0.70 sec | • Emergency RT. |
| Deceleration time. | $t_{decel} = -\frac{v_0}{a}$ | 17 | 1.1 sec | • Vehicle traveling at 16 km/h at onset of braking ($v_0$).<br>• Vehicle decelerates at a constant level of −4.0 m/sec$^2$ ($a$). |
| **Latest time to initiate braking for stopping at turn location.*** | $t_{stop} = t_{ERT} + t_{decel}$ | 18 | 1.8 sec | • No additional assumptions. |

* Measured from a turn point that is 7.6 m from the stop line.

### Milestone G—Last point for emergency maneuver in reaction to red-light runners

Milestone G represents the latest point at which it is possible to initiate at least a minimal evasive action in response to a potential collision with a red-light-running vehicle (task 2.5.3). Note that this duration is not intended to allow the subject vehicle to come to a stop or even to necessarily avoid the collision. It simply represents a minimal interval for the driver to see the potential problem and initiate a last-minute emergency maneuver that will have at least a minimal effect on the impending collision. The actual duration is an arbitrary value that is large enough to contain an emergency RT (0.7 sec) and a minimal amount of time for the vehicle to respond to the braking (1.3 sec). Table 105 lists equations and assumptions for Scenario 2—Left Turn on Yellow Light, Milestone G.

**Table 105. Scenario 2—Left Turn on Yellow Light, Milestone G, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Emergency perceptual-motor reaction time ($t_{ERT}$). | *Assumed value* | – | 0.70 sec | • Emergency RT. |
| Time for minimal response ($t_{response}$). | *Assumed value* | – | 1.3 sec | • See text above. |
| **Latest time to respond to hazard.*** | $t_{hazard} = t_{ERT} + t_{response}$ | 19 | 2.0 sec | No additional assumptions. |

* Measured from hypothetical collision point of 0.8 m before the turn point.

## SCENARIO 3—STRAIGHT ON YELLOW LIGHT

Figure 64 provides the timeline and calculated vehicle speed information for scenario 3. The key temporal milestones are described in table 106. Some milestones that are shown in figure 64 (e.g., intersection becomes visible) are not described in table 106 and do not have corresponding timestamps computed. These milestones either do not affect the scenario timing in a meaningful way or they cannot be computed because of insufficient information. They are included only to provide additional contextual information for understanding the timeline.

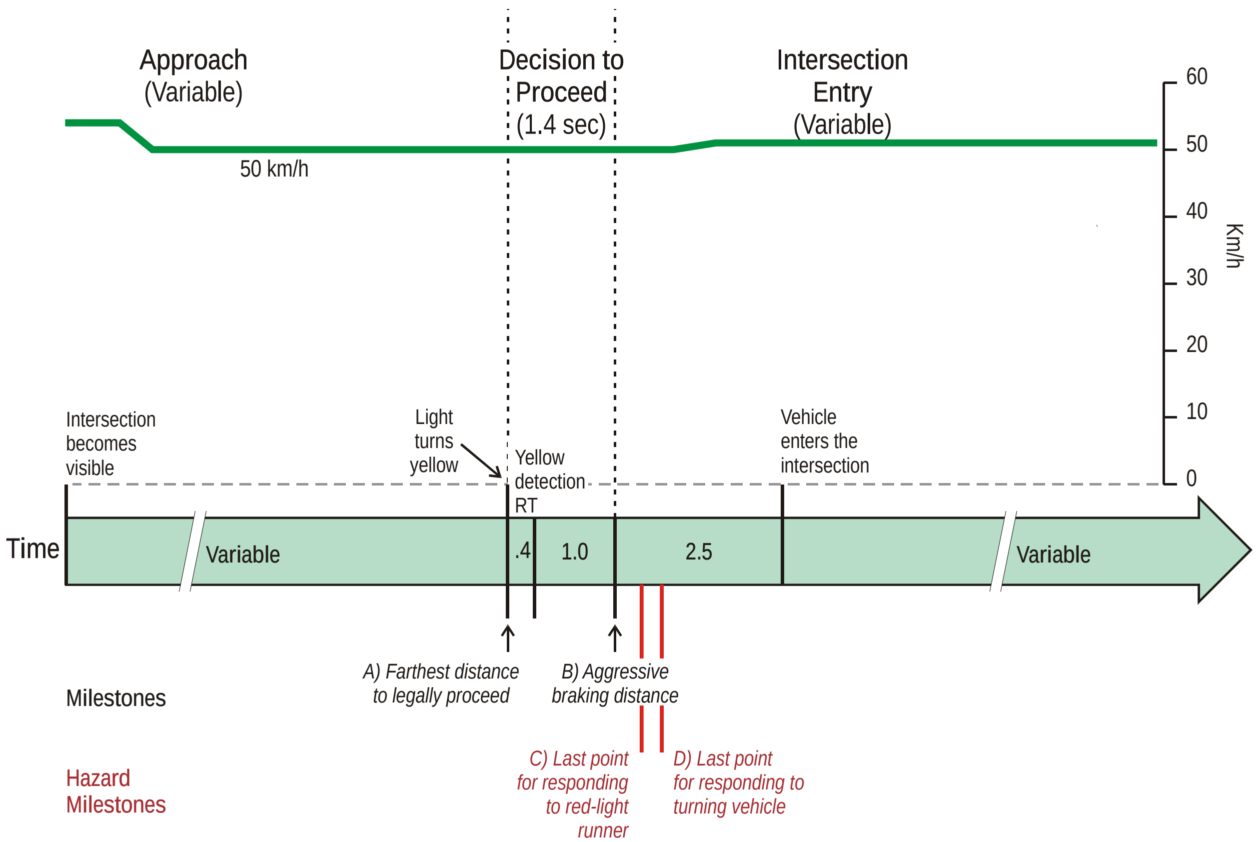



**Figure 64. Scenario 3—Straight on Yellow Light timeline depicting key temporal milestones.**

**Table 106. Scenario 3—Straight on Yellow Light description of key temporal milestones.**

| | Key Milestones | Description |
|---|---|---|
| A | Farthest distance to legally proceed. | This is the farthest distance away from the intersection that the driver can be and still make it into the intersection before the light turns red. It represents the *start* of the option zone in which drivers have the option to either proceed or to stop. Note that the light is assumed to turn yellow when the subject vehicle reaches this point. |
| B | Aggressive braking distance. | This provides the latest point at which the driver can begin decelerating and still maintain a moderately aggressive, nonemergency deceleration level for coming to a stop at the stop line. It represents the *end* of the option zone in which drivers have the option to either proceed or stop. |
| | **Hazard Milestones** | **Description** |
| C | Last point for emergency maneuver in reaction to red-light runners. | This represents the latest time by which the subject driver can detect and respond to the hazard in order to initiate at least a minimal evasive action (task 3.3.4). |
| D | Last point for emergency maneuver in reaction to oncoming traffic turning left at the last minute. | This represents the latest time by which the subject driver can detect and respond to oncoming traffic turning left at the last minute and make at least a minimal evasive action (task 3.3.5). |

### Milestone A—Farthest distance to legally proceed

Milestone A addresses the farthest distance away from the intersection that the driver can be and still make it into the intersection before the light turns red. It represents the start of the option zone in which drivers have the option to either proceed or to stop. Note that the light is assumed to turn yellow when the subject vehicle reaches this point. Also, note that the subject vehicle cannot begin the process of deciding whether to go until the yellow light onset has been detected. Table 107 lists equations and assumptions for Scenario 3—Straight on Yellow Light, Milestone A.

**Table 107. Scenario 3—Straight on Yellow Light, Milestone A, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Yellow light detection time ($t_{DRT}$).** | *Assumed value* | – | 0.4 sec | • Light detection time.[†] |
| Distance traveled during yellow phase. | $d_{yellow} = v_0 t_{yellow}$ | 20 | 56 m | • Yellow phase duration of 4 sec ($t_{yellow}$).<br>• Vehicle traveling at constant speed of 50 km/h ($v_0$). |
| Latest distance from stop line to be able to proceed legally. | $d_{proceed} = d_{yellow} - d_{int}$ | 21 | 50 m | • Signal turns red when vehicle is 1 m into the intersection ($d_{int}$). |
| **Time available for tasks 3.2.4 through 3.2.8 (option zone).** | $t_{task} = \frac{d_{proceed} - d_{stop}}{v_0} - t_{DRT}$ | 22 | 1.0 sec | • Vehicle traveling at constant speed of 50 km/h ($v_0$).<br>• $d_{stop}$ (3.9 sec) from Milestone B. |

[†]The detection time is based on the perception RT reported in studies in which drivers respond to a light-based event, such as the change in traffic light or the onset of brake lights. The value chosen (0.4 sec) is on the high end of observed values reported in Green (2000).[(30)]

## Milestone B—Aggressive braking distance

Milestone B indicates the latest point by which the driver can begin decelerating and still maintain a moderately aggressive, nonemergency deceleration level for coming to a stop at the stop line. It represents the end of the option zone in which drivers have the option to either proceed or stop; however, whether the driver stops or continues through the intersection depends on the outcome of segment 2 (*Decision to Proceed*). Thus, it is also the point by which tasks 3.2.5, 3.2.7, and 3.2.8 should be completed.

Table 108 lists equations and assumptions for Scenario 3—Straight on Yellow Light, Milestone B.

**Table 108. Scenario 3—Straight on Yellow Light, Milestone B, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Braking reaction time ($t_{BRT}$).** | *Assumed value* | – | 0.4 sec | • General motor RT. |
| Distance traveled during braking RT ($d_{BRT}$). | $d_{RT} = v_0 t_{BRT}$ | 23 | 6 m | • Vehicle traveling at constant speed of 50 km/h ($v_0$). |
| Braking time. | $t_{BR} = -\frac{v_0}{a}$ | 24 | 3.5 sec | • Vehicle traveling at 50 km/h at onset of braking ($v_0$).<br>• Vehicle decelerates at a constant level of −4.0 m/sec$^2$ (*a*).†<br>• Vehicle comes to a complete stop at the stop line. |
| Braking distance. | $d_{BR} = 0.5at_{BR}^2 + v_0 t_{BR}$ | 25 | 24 m | |
| Latest time to brake. | $t_{stop} = t_{BRT} + t_{BR}$ | 26 | 3.9 sec | |
| Latest distance to stop point for braking. | $d_{stop} = d_{BRT} + d_{BR}$ | 27 | 30 m | |
| **Vehicle enters the intersection.** | $t_{int} = \frac{d_{int}}{v_0}$ | 28 | 2.5 sec | • Vehicle traveling at constant speed of 50 km/h ($v_0$).<br>• Intersection entry occurs 6 m past the stop line ($d_{int.}$). |

†Due to the time-critical nature of stopping before the light turns red, a more aggressive deceleration was used. The Green Book (p. 111)(3) defines hard (emergency) braking to be 4.5 m/sec$^2$ and comfortable braking to be 3.4 m/sec$^2$. A level of 4.0 m/sec$^2$ is roughly in between these values and likely reflects an aggressive level of deceleration.

### Milestone C—Last point for emergency maneuver in reaction to red-light runners

Milestone C represents the latest point at which it is possible to initiate at least a minimal evasive action in response to a potential collision with a red-light-running vehicle (task 3.3.4). How it works is that an arbitrary cutoff point for responding to a potential hazard was selected (0.7 sec RT + 1.3 sec maneuver (table 109). This 2-sec interval allows a vehicle traveling at 50 km/h to slow to just more than 30 km/h and provides some time to alter the vehicle’s trajectory. Note that this interval may not allow the drivers to avoid a collision, but it will reduce the consequences of that collision. Also, an implicit assumption in this approach is that once the vehicle is within 2 sec of the potential collision point, it is no longer worthwhile to continue to systematically search for that hazard because any subsequent response will have little or no effect in mitigating the crash impact.

**Table 109. Scenario 3—Straight on Yellow Light, Milestone C, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Emergency perceptual-motor reaction time ($t_{ERT}$). | *Assumed value* | – | 0.70 sec | • Emergency RT. |
| Time for minimal response ($t_{response}$). | *Assumed value* | – | 1.3 sec | • See text above. |
| **Latest time to respond to hazard.*** | $t_{hazard} = t_{ERT} + t_{response}$ | 29 | 2.0 sec | No additional assumptions. |

* Measured from hypothetical collision point of 1.8 m into the intersection.

### Milestone D—Last point for emergency maneuver in reaction to oncoming traffic turning left at the last minute

Milestone D represents the latest point at which it is possible to initiate at least a minimal evasive action in response to a potential collision with a red-light-running vehicle (task 3.3.5). How it works is that an arbitrary cutoff point for responding to a potential hazard (0.7 sec RT + 1.3 sec) maneuver; was selected (table 110). This 2-sec interval allows a vehicle traveling at 50 km/h to slow to just more than 30 km/h and provides some time to alter the vehicle's trajectory. Note that this interval may not allow the drivers to avoid a collision, but it will reduce the consequences of that collision. Also, an implicit assumption in this approach is that once the vehicle is within 2 sec of the potential collision point, it is no longer worthwhile to continue to systematically search for that hazard because any subsequent response will have little or no effect in mitigating the crash impact.

**Table 110. Scenario 3—Straight on Yellow Light, Milestone D, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Emergency perceptual-motor reaction time ($t_{ERT}$). | *Assumed value* | – | 0.70 sec | • Emergency RT. |
| Time for minimal response ($t_{response}$). | *Assumed value* | – | 1.3 sec | • See text above. |
| **Latest time to respond to hazard.*** | $t_{hazard} = t_{ERT} + t_{response}$ | 30 | 2.0 sec | No additional assumptions. |

Measured from hypothetical collision point of 5.4 m into the intersection.

## SCENARIO 4—STRAIGHT ON GREEN LIGHT

Figure 65 provides the timeline and calculated vehicle speed information for scenario 4. The key temporal milestones are described in table 111. Some milestones shown in figure 65 (e.g., intersection becomes visible) are not described in table 111 and do not have corresponding timestamps computed. These milestones either do not affect the scenario timing in a meaningful way, or they cannot be computed because of insufficient information. They are included only to provide additional contextual information for understanding the timeline.

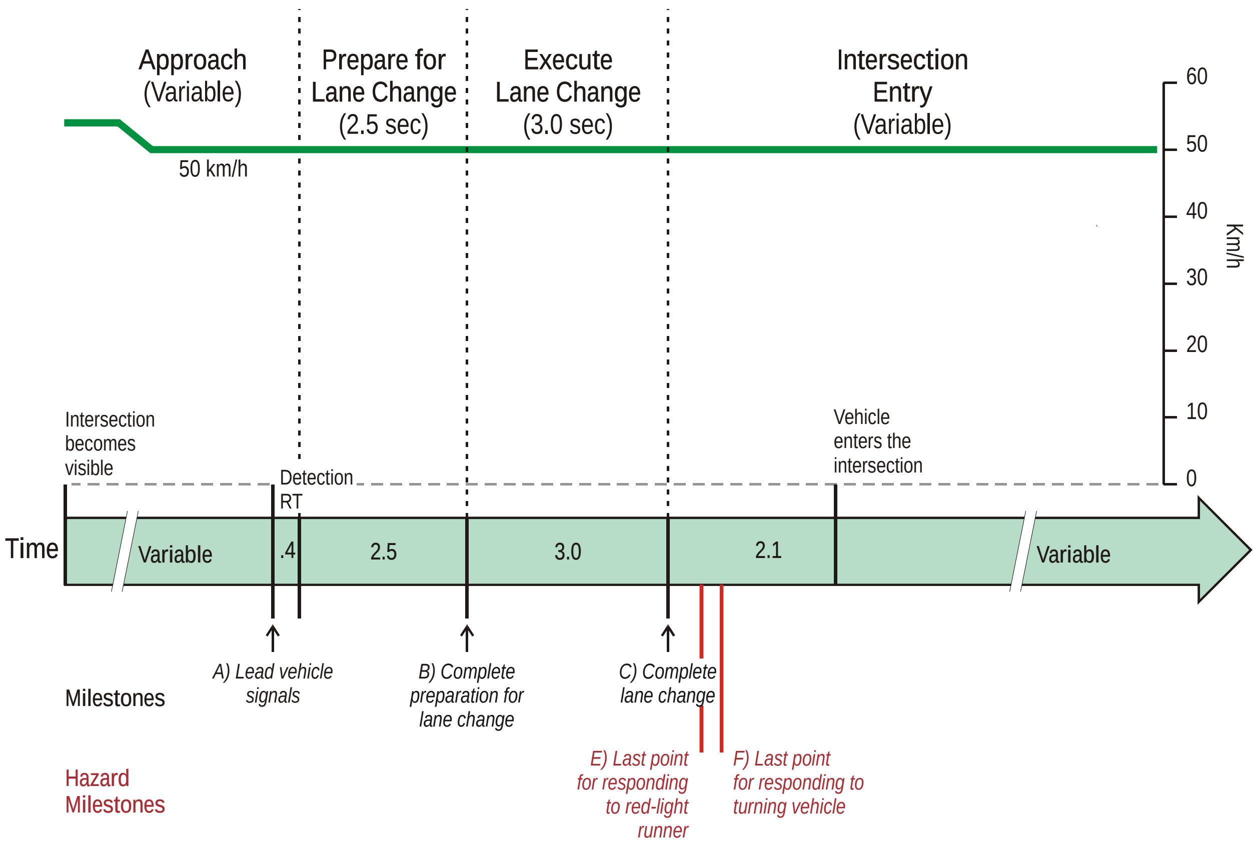



**Figure 65. Scenario 4—Straight on Green Light timeline depicting key temporal milestones.**

One noteworthy point is that most key milestones in this scenario are arbitrarily set in time. This is because the lead vehicle braking event (which triggers the need to change lanes) can happen at any point in time, which means that essentially any amount of time can be allotted to complete the scenario tasks; however, our goal was to maintain a challenging and rapid task pacing. This was done by first determining the time intervals and scenario assumptions that would achieve this objective, and then working backwards from there to set the overall scenario timing. In particular, we started with a 2.5 sec time-to-collision (TTC) between the subject vehicle and the turning vehicle in the originating lane as the endpoint to the lane change, then went backward in the timeline to accommodate additional intervals for the "executing lane changing" (2.0 sec), "preparing for lane changing" (2.5 sec), and "detect brake lights" (0.4 sec) events in order to set the lead vehicle braking milestone. Note that the time interval durations are explained below in the individual milestone discussions. In addition, two scenario assumptions were made in order to promote rapid pacing of the lane change: that the lead vehicle does not brake until the subject vehicle is close enough to the intersection so that the lane change must be completed quickly and that there is another vehicle behind the subject vehicle in the destination lane, which requires the subject vehicle to keep traveling at speed to make the lane change possible.

Note that for the remainder of the scenario 4 milestone calculation discussion, the term "lead vehicle" refers to the vehicle in front of the subject vehicle in the originating lane.

**Table 111. Scenario 4—Straight on Green Light description of key temporal milestones.**

| Key Milestones | | Description |
|---|---|---|
| A | Driver detects lead vehicle braking. | This milestone is the last task conducted as part of the *Approach Segment*, and it prompts the subject driver to determine if it is possible to change lanes in the next segment (Prepare for Lane Change). |
| B | Complete preparation for lane change. | This marks the end/duration of the *Prepare for Lane Change Segment*. |
| C | Complete lane change. | This marks the end/duration of the *Execute Lane Change Segment*. It also corresponds with the point at which the subject vehicle is no longer in potential conflict with the turning vehicle in the original lane. |
| **Hazard Milestones** | | **Description** |
| D | Last point for emergency maneuver in reaction to red-light runners. | This represents the latest time by which the subject driver can detect and respond to the hazard in order to initiate at least a minimal evasive action (task 4.4.5). |
| E | Last point for emergency maneuver in reaction to oncoming traffic turning left at the last minute. | This represents the latest time by which the subject driver can detect and respond to oncoming traffic turning left at the last minute and make at least a minimal evasive action (task 4.4.6). |

### Milestone A—Driver detects lead vehicle braking

Milestone A is the last task conducted as part of the *Approach* segment, and it prompts the subject driver to determine if it is possible to change lanes in the next segment (*Prepare for Lane Change*) (table 112).

**Table 112. Scenario 4—Straight on Green Light, Milestone A, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Time required for lead vehicle to decelerate to a stop ($t_{decelL}$). | $t_{decelL} = -\frac{v_0}{a}$ | 31 | 4.1 sec† | • Lead vehicle traveling at constant speed of 50 km/h at onset of braking ($v_0$).<br>• Lead vehicle decelerates at a level of −3.4 m/sec$^2$ ($a$). |
| **Detect brake lights (detection RT $t_{DRT}$).** | *Assumed value* | – | 0.4 sec | • Light detection time.†† |
| Lead vehicle deceleration distance. | $d_{decelL} = -\frac{v_0^2}{2a}$ | 32 | 28 m† | • Lead vehicle traveling at constant speed of 50 km/h at onset of braking ($v_0$).<br>• Lead vehicle decelerates at a level of −3.4 m/sec$^2$ ($a$). |

†The lead vehicle deceleration trajectory is required for the calculation of the 2.5-sec TTC separation between the lead and subject vehicles at the completion of the lane change.

††The detection time is based on the perception RT reported in studies in which drivers respond to a light-based event, such as the change in traffic light or the onset of brake lights. The value chosen (0.4 sec) is on the high end of observed values reported in Green (2001).[30]

### Milestone B—Complete preparation for lane change

Milestone B marks the end/duration of the *Prepare for Lane Change* segment (table 113).

**Table 113. Scenario 4—Straight on Green Light, Milestone B, equations and assumptions.**

| Description | Equation | Result | Assumptions |
|---|---|---|---|
| **Duration of activities related to preparing for the lane change ($t_{prepLC}$).** | *Assumed value* | 2.5 sec | • The lane change is hurried.† |

†This value is based on research by Mourant and Donohue,[32] which was conducted on novice drivers making left-side lane changes and found that drivers took an average of 2.4 sec to complete the visual scanning that precedes a lane change. Also, more recent research indicates that most glances related to prelane scanning behavior can be captured in an analysis window encompassing the 3 sec just before the lane-change onset.[24]

### Milestone C—Complete lane change

Milestone C marks the end/duration of the activities related to maneuvering the subject vehicle from the originating lane to the destination lane. It also corresponds with the point at which the subject vehicle is no longer in potential conflict with the lead vehicle in the originating lane. A key assumption is that the lane change is completed by the point in time where there is a 2.5-sec TTC between these vehicles (table 114).

**Table 114. Scenario 4—Straight on Green Light, Milestone C, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Duration of the lane change ($t_{execLC}$). | *Assumed value* | – | 3.0 sec | • The lane change is hurried.† |
| **Time to stop line at completion of lane change ($t_{stopline}$).** | $t_{stopline} = t_{TTC} - \frac{5.8}{v_0}$ | 33 | 2.1 sec | • Lane change completed when TTC with lead vehicle is 2.5 sec ($t_{TTC}$).<br>• Rear bumper of lead vehicle 5.8 m from stop line.<br>• Vehicle traveling at constant speed of 50 km/h. |

†This value is slightly faster than the low end of the range for observed lane change durations in city environments, which have 3.5 to 3.4 sec as a lower bound and a mean/modal duration of around 6 sec.(33,34) The reason why a shorter duration was assumed was to reflect the hurried pacing of the lane change because the subject vehicle must get out of the way of the stopping lead vehicle in the originating lane. Also, we conducted informal pilot testing in a driving simulator with three experienced drivers and found that they were consistently able to complete a comparable lane-change maneuver in around 2.5 to 3 sec. As a practical matter, the duration of this segment has little effect on the scenario because lengthening this interval would just mean that the lane change has to start farther back from the intersection.

### Milestone D—Last point for emergency maneuver in reaction to red-light-runners

Milestone D represents the latest point at which it is possible to initiate at least a minimal evasive action in response to a potential collision with a red-light-running vehicle (task 4.4.5). It works with an arbitrary cutoff point for responding to a potential hazard (0.7 sec RT + 1.3 sec maneuver). This 2-sec interval allows a vehicle traveling at 50 km/h to slow to just more than 30 km/h and provides some time to alter the vehicle's trajectory. Note that this interval may not allow the drivers to avoid a collision, but it will reduce the consequences of that collision. Also, an implicit assumption in this approach is that once the vehicle is within 2 sec of the potential collision point, it is no longer worthwhile to continue to search systematically for that hazard because any subsequent response will have little or no effect in mitigating the crash impact. Table 115 lists equations and assumptions for Scenario 4—Straight on Green Light, Milestone D.

**Table 115. Scenario 4—Straight on Green Light, Milestone D, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Emergency perceptual-motor reaction time ($t_{ERT}$). | *Assumed value* | – | 0.70 sec | • Emergency RT |
| Time for minimal response ($t_{response}$). | *Assumed value* | – | 1.3 sec | • See text above |
| **Latest time to respond to hazard.*** | $t_{hazard} = t_{ERT} + t_{response}$ | 34 | 2.0 sec | No additional assumptions. |

* Measured from the hypothetical collision point of 1.8 m into the intersection.

### Milestone E—Last point for emergency maneuver in reaction to oncoming traffic turning left at the last minute

Milestone E represents the latest point at which it is possible to initiate at least a minimal evasive action in response to a potential collision with a red-light-running vehicle (task 4.4.6). It works with an arbitrary cutoff point (0.7 sec RT + 1.3 sec) for responding to a potential hazard maneuver. This 2-sec interval allows a vehicle traveling at 50 km/h to slow to just more than 30 km/h and provides some time to alter the vehicle’s trajectory. Note that this interval may not allow the drivers to avoid a collision, but it will reduce the consequences of that collision. Also, an implicit assumption in this approach is that when the vehicle is within 2 sec of the potential collision point, it is no longer worthwhile to continue to search systematically for that hazard because any subsequent response will have little or no effect in mitigating the crash impact. Table 116 lists equations and assumptions for Scenario 4—Straight on Green Light, Milestone E.

**Table 116. Scenario 4—Straight on Green Light, Milestone E, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Emergency perceptual-motor reaction time ($t_{ERT}$). | *Assumed value* | – | 0.70 sec | • Emergency RT. |
| Time for minimal response ($t_{response}$). | *Assumed value* | – | 1.3 sec | • See text above. |
| **Latest time to respond to hazard.*** | $t_{hazard} = t_{ERT} + t_{response}$ | 35 | 2.0 sec | No additional assumptions. |

* Measured from the hypothetical collision point of 5.4 m into the intersection.

## SCENARIO 5—RIGHT TURN ON GREEN

Figure 66 provides the timeline and calculated vehicle speed information for scenario 5. The key temporal milestones are described in table 117. Some milestones that are shown in figure 66 (e.g., intersection becomes visible) are not described in table 117 and do not have corresponding timestamps computed. These milestones either do not affect the scenario timing in a meaningful way or they cannot be computed because of insufficient information. They are included only to provide additional contextual information for understanding the timeline.

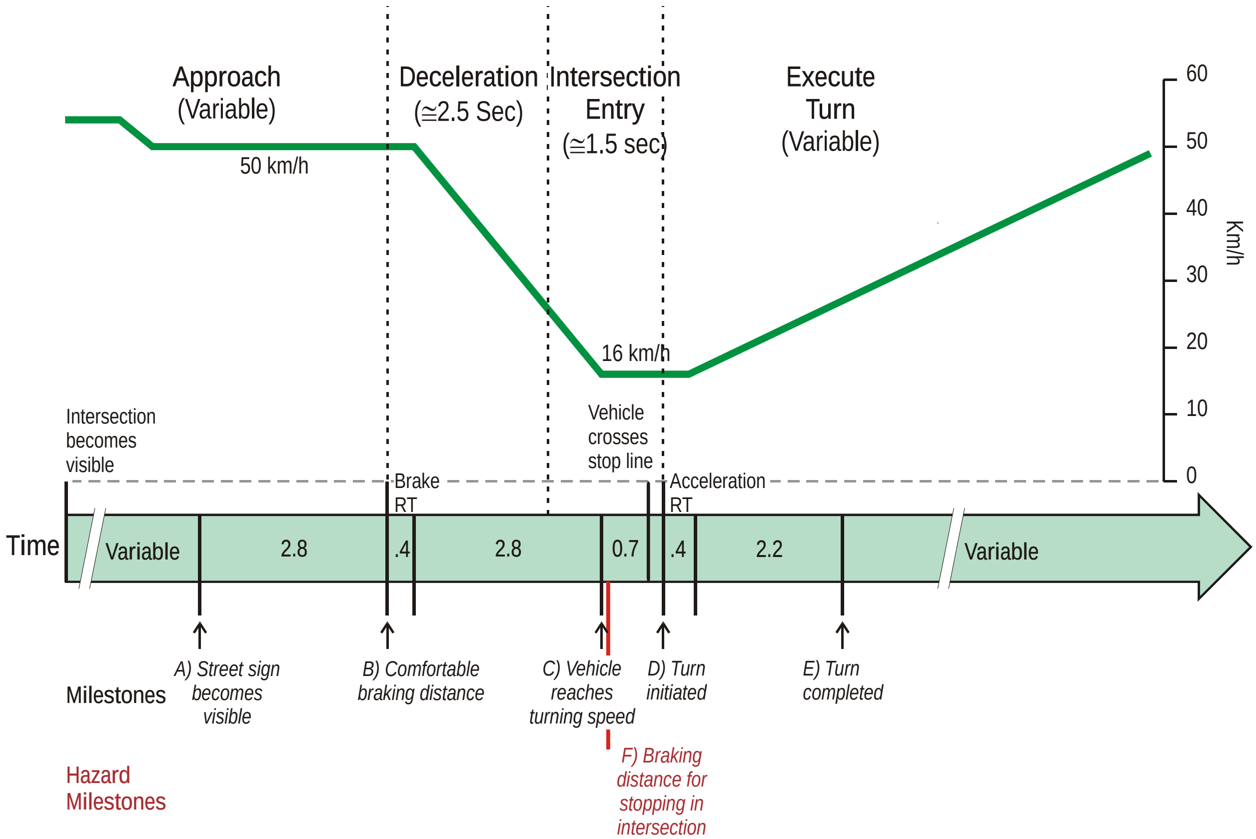



**Figure 66. Scenario 5—Right Turn on Green Light timeline depicting key temporal milestones.**

**Table 117. Scenario 5—Right Turn on Green Light description of key temporal milestones.**

| Key Milestones | | Description |
|---|---|---|
| A | Street sign becomes readable. | This provides the earliest point at which the driver can begin determining if the intersection is the correct turn intersection (task 5.1.7). In conjunction with the braking distance (next milestone), this milestone indicates the time available to perform tasks 5.1.7 and 5.1.8. |
| B | Comfortable braking distance. | This provides the latest point at which the driver can begin decelerating and maintain a comfortable deceleration level. It also represents the time point before which the driver should have completed tasks 5.1.5 through 5.1.8. |
| C | Vehicle reaches turning speed. | This is the point at which the subject vehicle reaches the turning speed and then continues towards the turn location at a constant speed. |
| D | Initiate turn. | This is the point at which the subject vehicle arrives at the location where it is necessary to begin the right turn. It also marks the end of the Intersection Entry Segment. |
| E | Turn completed. | This represents the interval in which the subject vehicle is actively engaged in turning (tasks 5.4.1 through 5.4.4). |
| F | Braking distance for stopping in the intersection. | This is the last point in time that the subject vehicle can still come to a stop in the intersection before starting the turn trajectory. It represents the point by which the driver must have determined that it is safe to proceed (e.g., there are no conflicts with red-light-running traffic–task 5.3.6, oncoming left-turning vehicles–task 5.3.7, or hazards in the turn path–task 5.3.8). |

## Milestone A—Street sign becomes readable

Milestone A provides the earliest point at which the driver can begin determining if the intersection is the correct turn intersection (task 5.1.7) and, in conjunction with the deceleration cutoff point (next milestone), it indicates the time available to perform tasks 5.1.5 through 5.1.8. Table 118 lists equations and assumptions for Scenario 5—Right Turn on Green Light, Milestone A.

**Table 118. Scenario 5—Right Turn on Green Light, Milestone A, equations and assumptions.**

| Description | Equations | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Distance from intersection in which street sign becomes readable. | $d_{read} = 0.48\text{ m} \times \text{height of text in mm}$ | 36 | 73 m | • Street sign letter height of 152.4 mm (6 inches).† <br> • Symbol legibility distance of 12.2 m per 25.4 mm (40 ft per in) of text height.†† |
| Distance traveled to braking distance. | $d_{cutoff} = d_{read} - d_{decel}$ | 37 | 39 m | • Vehicle is traveling at a constant speed of 50 km/h. <br> • $d_{decel}$ (34 m) from Milestone B. |
| **Time of travel to braking distance.** | $t_{cutoff} = \dfrac{d_{cutoff}}{v_0}$ | 38 | 2.8 sec | • Vehicle is traveling at a constant speed of 50 km/h. |

†MUTCD reference for letter height: p. 2D-17. (4) ††MUTCD reference for sign distance relative to letter height: p. 2A-7. (4)

### Milestone B–Comfortable braking distance

Milestone B provides the latest point at which the driver can begin decelerating and maintain a comfortable deceleration level. It also represents the time the subject driver has to complete tasks 5.1.7 and 5.1.8 when the street signs become readable. Table 119 lists equations and assumptions for Scenario 5—Right Turn on Green Light, Milestone B.

**Table 119. Scenario 5—Right Turn on Green Light, Milestone B, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Braking reaction time ($t_{BRT}$).** | *Assumed value* | – | 0.4 sec | • General motor RT. |
| **Deceleration Interval (excludes Braking RT).** | $t_{decel} = -\frac{v_0}{a}$ | 39 | 4.1 sec | • Vehicle traveling at 50 km/h at onset of braking ($v_0$).<br>• Vehicle decelerates at a constant level of −3.4 m/sec$^2$ ($a$).<br>• Projected deceleration endpoint (0 km/sec) is the stop line.† |
| Deceleration distance (excludes Braking RT). | $d_{decel} = 0.5at_{decel}^2 + v_0 t_{decel}$ | 40 | 28 m | • Vehicle traveling at 50 km/h at onset of braking ($v_0$).<br>• Vehicle decelerates at a constant level of −3.4 m/sec$^2$ ($a$). |

†An endpoint of 0 km/h at the stop line was used to calculate the starting point for braking, with the assumption that the vehicle continues at a constant speed after reaching 16 km/h. This endpoint was selected instead of the turn location because it is more conservative (drivers can stop more easily for hazards at the crosswalk). At a practical level, however, the difference between this endpoint and an endpoint of 16 km/h at the turn location is negligible.

### Milestone C—Vehicle reaches turning speed

Milestone C represents the point at which the subject vehicle reaches the turning speed and then continues towards the turn location at a constant speed. Table 120 lists equations and assumptions for Scenario 5—Right Turn on Green Light, Milestone C.

**Table 120. Scenario 5—Right Turn on Green Light, Milestone C, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Time required to decelerate to turning speed ($t_{tv}$).** | $t_{tv} = \dfrac{v_f - v_0}{a}$ | 41 | 2.8 sec | • Vehicle decelerates at a constant level of −3.4 m/sec$^2$ ($a$) from 50 km/h ($v_0$) to 16 km/h ($v_f$). |
| Distance traveled until turn speed reached. | $d_{tv} = 0.5at_{tv}^2 + v_0 t_{tv}$ | 42 | 25 m | |

## Milestone D—Initiate turn

Milestone D is the point at which the subject vehicle arrives at the location where it is necessary to begin the right turn. It also marks the end of the *Intersection Entry* segment. Table 121 lists equations and assumptions for Scenario 5—Right Turn on Green Light, Milestone D.

**Table 121. Scenario 5—Right Turn on Green Light, Milestone D, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Time required to travel from point at which turning speed reached until stop line reached. | $t_{stopline} = \dfrac{d_{decel} - d_{tv}}{v}$ | 43 | 0.7 sec | • $d_{decel}$ (28 m) from Milestone B.<br>• $d_{tv}$ (25 m) from Milestone C.<br>• Vehicle traveling at constant speed of 16 km/h ($v$). |
| Distance to turn point from stop line ($d_{TP}$). | *Assumed value* | – | 0.4 m | • Value determined from roadway geometry. |
| **Time required to travel from stop line to turn point at constant speed.** | $t_{TP} = \dfrac{d_{TP}}{v}$ | 44 | 0.1 sec | • Vehicle traveling at constant speed of 16 km/h ($v$). |

## Milestone E—Turn completed

Milestone E represents the interval in which the subject vehicle is actively engaged in turning (tasks 5.4.1 through 5.4.4). Table 122 lists equations and assumptions for Scenario 5—Right Turn on Green Light, Milestone E.

**Table 122. Scenario 5—Right Turn on Green Light, Milestone E, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Acceleration reaction time ($t_{ART}$).** | *Assumed value* | – | 0.4 sec | • General motor RT.† |
| Distance traveled during acceleration reaction time. | $d_{ART} = v_0 t_{ART}$ | 45 | 1.8 m | • Vehicle traveling at constant speed of 16 km/h ($v_0$). |
| Distance through turn. | $d_{turn} = d_{path} - d_{ART}$ | 46 | 14 m | • Total path distance through the intersection of 16.3 m including vehicle length ($d_{path}$). |
| **Time required to accelerate through turn.** | $t_{turn} = \frac{-v_0 + \sqrt{v_0^2 + 2ad_{turn}}}{a}$ | 47 | 2.2 sec | • Vehicle accelerates at a constant level of 2.0 m/sec$^2$ ($a$). |

†The cognitive/perceptual elements of this action are defined as being part of the preceding tasks. More specifically, the decision to turn is the culmination of tasks 2.4.5 through 2.4.8 of the preceding segment; thus, this RT simply represents the time needed to press the accelerator and start turning the steering wheel following this decision.

## Milestone F—Braking distance for stopping in the intersection

Milestone F is the last point in time that the subject vehicle can still come to a stop in the intersection before starting the turn trajectory. It represents the point by which the driver must have determined that it is safe to proceed (e.g., there are no conflicts with red-light-running traffic—task 5.3.6, oncoming left-turning vehicles—task 5.3.7, or hazards in the turn path—task 5.3.8). Table 123 lists equations and assumptions for Scenario 5—Right Turn on Green, Milestone F.

**Table 123. Scenario 5—Right Turn on Green Light, Milestone F, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Emergency perceptual-motor reaction time ($t_{ERT}$). | *Assumed value* | – | 0.70 sec | • Emergency RT. |
| Deceleration time. | $t_{decel} = -\frac{v_0}{a}$ | 48 | 1.0 sec | • Vehicle traveling at 16 km/h at onset of braking ($v_0$). • Vehicle decelerates at a constant level of −4.0 m/sec$^2$ ($a$). |
| **Latest time to initiate braking for stopping at intersection entry.*** | $t_{stop} = t_{ERT} + t_{decel}$ | 49 | 1.7 sec | No additional assumptions. |

* Measured from an intersection entry point that is 5 m from the stop line.

## SCENARIO 6—RIGHT TURN ON RED LIGHT

Figure 67 provides the timeline and calculated vehicle speed information for scenario 6. The key temporal milestones are described in table 124. Some milestones shown in figure 67 (e.g., intersection becomes visible) are not described in table 124 and do not have corresponding timestamps computed. These milestones either do not affect the scenario timing in a meaningful way, or they cannot be computed because of insufficient information. They are included only to provide additional contextual information for understanding the timeline.

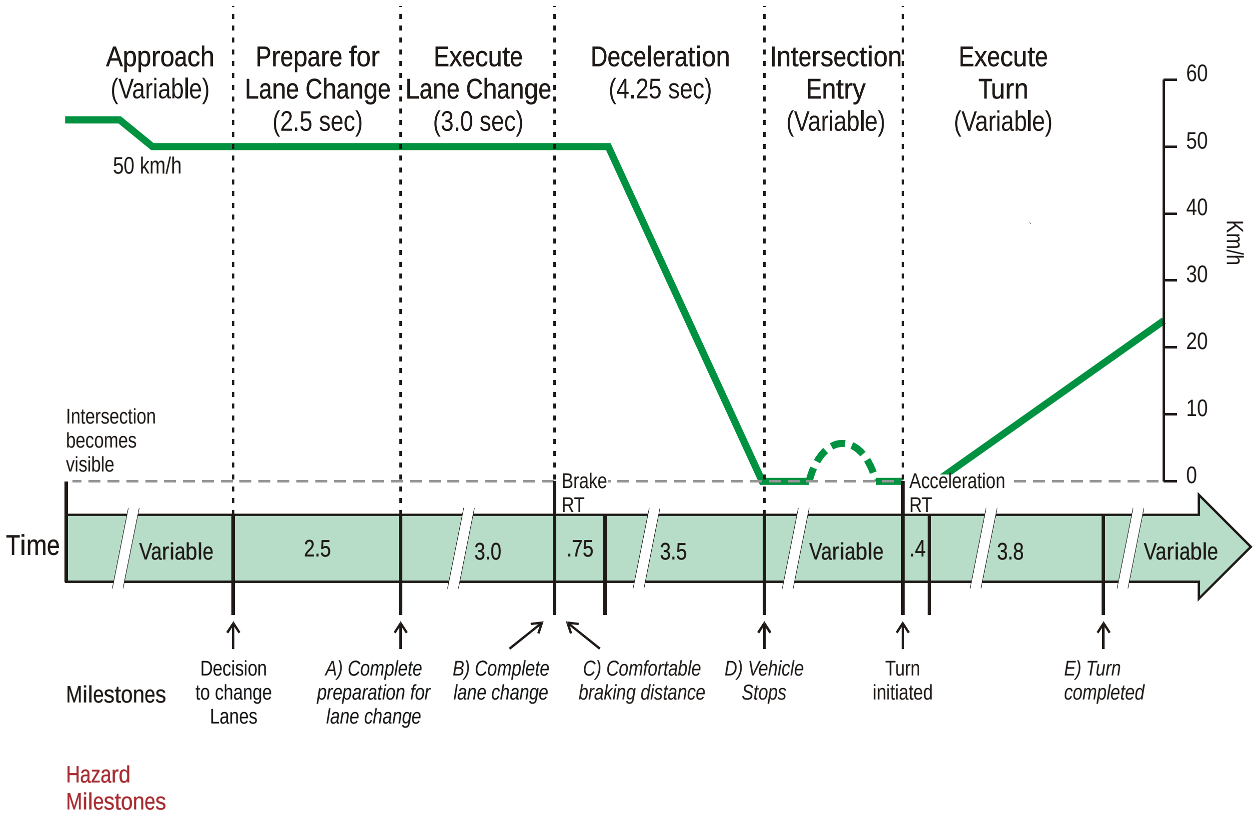



**Figure 67. Scenario 6—Right Turn on Red Light timeline depicting key temporal milestones.**

**Table 124. Scenario 6—Right Turn on Red Light description of key temporal milestones.**

| Key Milestones | | Description |
|---|---|---|
| A | Complete preparation for lane change. | This marks the end/duration of the *Prepare for Lane Change* segment. |
| B | Complete lane change. | This marks the end/duration of the *Execute Lane Change* segment. |
| C | Braking distance. | This provides the latest point at which the driver can begin decelerating based on an aggressive deceleration level. |
| D | Vehicle stops. | This is the point where the vehicle comes to a complete stop at the stop line and marks the endpoint of segment 4 (Stop). |
| E | Turn completed. | This represents the interval in which the subject vehicle is actively engaged in turning (tasks 6.6.1 through 6.6.4), following the motor RT. |

### Milestone A—Complete preparation for lane change

Milestone A marks the end/duration of the *Prepare for Lane Change* segment. Table 125 lists equations and assumptions for Scenario 6—Right Turn on Red Light.

**Table 125. Scenario 6—Right Turn on Red Light, Milestone A, equations and assumptions.**

| Description | Equation | Result | Assumptions |
|---|---|---|---|
| **Duration of activities related to preparing for the lane change.** | *Assumed value* | 2.5 sec | • The lane change is hurried.† |

†This value is based on research by Mourant and Donohue,(32) which was conducted on novice drivers making left-side lane changes and found that drivers took an average of 2.4 sec to complete the visual scanning that precedes a lane change. More recent research indicates that most glances related to prelane scanning behavior can be captured in an analysis window encompassing the 3 sec just before the lane-change onset.(24)

### Milestone B—Complete lane change

Milestone B marks the end/duration of the activities related to maneuvering the subject vehicle from the originating lane to the destination lane. Table 126 lists equations and assumptions for Scenario 6—Right Turn on Red Light.

It is noteworthy that the driver is not assumed to begin decelerating until after the lane change is complete. This assumption is based partly on the fact that there is a following vehicle in the destination lane that is traveling at full speed and the subject vehicle must stay ahead of it. At a more practical level, keeping these components separate simplifies the allocation of tasks among the scenario segments.

**Table 126. Scenario 6—Right Turn on Red Light, Milestone B, equations and assumptions.**

| Description | Equation | Result | Assumptions |
|---|---|---|---|
| **Duration of the lane change.** | *Assumed value* | 3.0 sec | • The lane change is hurried.† |

†This value is slightly faster than the low end of the range for observed lane change durations in city environments, which have 3.5 to 3.4 sec as a lower bound and a mean/modal duration of around 6 sec.[33, 34] The reason why a shorter duration was assumed was to reflect the hurried pacing of the lane change because the subject vehicle must get out of the way of the slowing/stopping lead vehicle in the originating lane. Also, the researchers conducted informal pilot testing in a driving simulator with three experienced drivers and found that they were consistently able to complete a comparable lane-change maneuver in around 2.5 to 3 sec. As a practical matter, the duration of this segment has little effect on the scenario because lengthening this interval would just mean that the lane change has to start farther back from the intersection.

## Milestone C—Braking distance

Milestone C provides the latest point at which the driver can begin decelerating based on an aggressive deceleration level. Table 127 lists equations and assumptions for Scenario 6—Right Turn on Red Light, Milestone C.

**Table 127. Scenario 6—Right Turn on Red Light, Milestone C, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Braking reaction time ($t_{BRT}$). | *Assumed value* | – | 0.75 sec | • Perceptual/cognitive and motor RT.† |
| **Deceleration interval (excludes the Braking RT).** | $t_{decel} = -\frac{v_0}{a}$ | 50 | 3.5 sec | • Vehicle traveling at 50 km/h at onset of braking ($v_0$).<br>• Vehicle decelerates at a constant level of −4.0 m/sec$^2$ ($a$).††<br>• Vehicle comes to a complete stop at the stop line. |

†A response time that includes both a perceptual/cognitive and motor component was used for this milestone because these elements are not completed in the previous segment as is the case in other instances in which just the motor RT is used. Because there are no data on comparable situations (i.e., recognize that the vehicle is close enough to the intersection and initiate braking), this value is based on a 0.75 sec RT that represents RTs for common expected events,[30] which at least share some features in common with the current situation. In particular, the subject driver's task is relatively simple (recognizing that the vehicle is close enough to stop; see scenario 6, task analysis table), and the upcoming intersection is also expected.

††A deceleration level that is more aggressive than the comfortable deceleration level used in most of the other stopping/deceleration tasks was used. This is because the driver's preoccupation with the preceding lane-change maneuver is assumed to delay the driver's ability to identify and respond to the onset of the comfortable braking distance.

### Milestone D—Vehicle stops

Milestone D represents the point where the vehicle comes to a complete stop at the stop line and marks the endpoint of segment 4 (*Stop*). Table 128 lists equations and assumptions for Scenario 6—Right Turn on Red Light, Milestone D.

**Table 128. Scenario 6—Right Turn on Red Light, Milestone D, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Time to stop line once decision is made to stop.** | $t_{stop} = t_{BRT} + t_{decel}$ | 51 | 4.2 sec | • Vehicle comes to a complete stop at the stop line.<br>• $t_{BRT}$ and $t_{decel}$ from Milestone C. |

### Milestone E—Turn completed

Milestone E represents the interval in which the subject vehicle is actively engaged in turning (tasks 6.6.1 through 6.6.4), following the motor RT. Table 129 lists equations and assumptions for Scenario 6—Right Turn on Red Light, Milestone E.

**Table 129. Scenario 6—Right Turn on Red Light, Milestone E, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Acceleration reaction time ($t_{ART}$).** | *Assumed value* | – | 0.4 sec | • General motor RT.† |
| **Time to complete turn.** | $t_{turn} = \sqrt{\frac{2d_{turn}}{a}} + t_{ART}$ | 52 | 3.8 sec | • Distance from turn location to completion point is 11.3 m ($d_{turn}$) including vehicle length<br>• Vehicle accelerates at a constant level of 2.0 m/sec$^2$ ($a$). |

## SCENARIO 7—STOP ON RED LIGHT

Figure 68 provides the timeline and calculated vehicle speed information for scenario 7. The key temporal milestones are described in table 130. Some milestones shown in figure 68 (e.g., intersection becomes visible) are not described in table 130 and do not have corresponding timestamps computed. These milestones either do not affect the scenario timing in a meaningful way or they cannot be computed because of insufficient information. They are included only to provide additional contextual information for understanding the timeline.

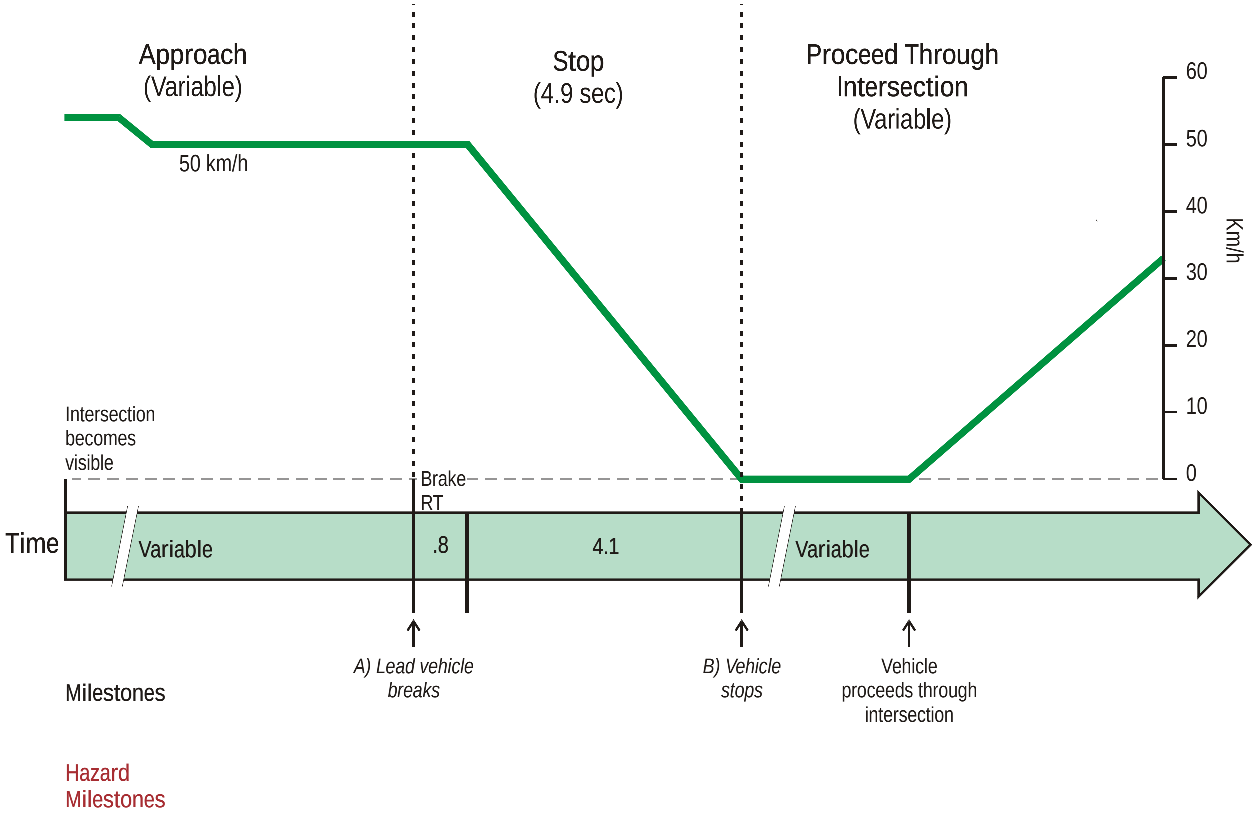



**Figure 68. Scenario 7—Stop on Red Light timeline depicting key temporal milestones.**

**Table 130. Scenario 7—Stop on Red Light description of key temporal milestones.**

| Key Milestones | | Description |
|---|---|---|
| A | Driver detects and responds to lead vehicle braking. | This occurs when the subject driver detects/confirms that the lead vehicle has begun stopping for the red light and begins decelerating in response. |
| B | Vehicle stops. | This is the point where the vehicle comes to a complete stop at the stop line and marks the endpoint of segment 2 (Stop). |

### Milestone A—Driver detects and responds to lead vehicle braking

Milestone A occurs when the subject driver detects/confirms that the lead vehicle has begun stopping for the red light and begins decelerating in response. Note that the lead vehicle braking distance does not include an RT component because the brake lights (which indicate the need to respond to the lead vehicle) do not illuminate until after the RT occurs. Table 131 lists equations and assumptions for Scenario 6—Stop on Red Light, Milestone A.

**Table 131. Scenario 7—Stop on Red Light, Milestone A, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| Lead vehicle comfortable braking distance. | $t_{BRL} = -\frac{v_0}{a}$ | 53 | 4.1 sec | • Lead vehicle traveling at constant speed of 50 km/h at onset of braking ($v_0$).<br>• Lead vehicle decelerates at a level of −3.4 m/sec$^2$ ($a$). |
| **Yellow light detection time ($t_{DRT}$).** | *Assumed value* | – | 0.4 sec | • Light detection time.† |
| **Braking reaction time ($t_{BRT}$).** | *Assumed value* | – | 0.4 sec | • General motor RT. |
| Distance between the lead vehicle and subject vehicle at time of lead-vehicle braking. | $d_{\Delta} = v_0 t_{gap}$ | 54 | 28 m | • Vehicles traveling at constant speed of 50 km/h at onset of lead vehicle braking ($v_0$).<br>• 2-sec gap between vehicles ($t_{gap}$) is assumed. |

†The detection time is based on the perception RT reported in studies in which drivers respond to a light-based event, such as the change in traffic light or the onset of brake lights. The value chosen (0.4 sec) is on the high end of observed values reported in Green (2000).[30]

### Milestone B—Vehicle stops

Milestone B represents the point where the vehicle comes to a complete stop at the stop line and marks the endpoint of segment 2, *Stop*. Table 132 lists equations and assumptions for Scenario 7—Stop on Red Light, Milestone B.

**Table 132. Scenario 7—Stop on Red Light, Milestone B, equations and assumptions.**

| Description | Equation | Eq. No. | Result | Assumptions |
|---|---|---|---|---|
| **Deceleration time ($t_{decel}$).** | $t_{decel} = -\frac{v_0}{a}$ | 55 | 4.1 sec | • Vehicle traveling at 50 km/h at onset of braking ($v_0$).<br>• Vehicle decelerates at a constant level of −3.4 m/sec$^2$ ($a$). |
| Time to stop line once decision is made to stop. | $t_{stop} = t_{BRT} + t_{DRT} + t_{decel}$ | 56 | 4.9 sec | • Vehicle comes to a complete stop 1 m from the rear bumper of the lead vehicle (6.8 m from the stop line).<br>• $t_{BRT}$ (0.4 sec) and $t_{DRT}$ (0.4 sec) from Milestone A. |

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