TRR
JOURNAL OF THE TRANSPORTATION RESEARCH BOARD

*Network Operations and Congestion*

Transportation Research Record
2019, Vol. 2673(4) 685–696

DOI: 10.1177/0361198119837506
journals.sagepub.com/home/trr
SAGE

# Traffic Signal Phasing Problem-Solving Rationales of Professional Engineers Developed from Eye-Tracking and Clinical Interviews

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## Abstract

There is a lack of knowledge on the way transportation engineering practitioners engage with various Contextual Representations (CRs) to solve traffic engineering design problems. CRs such as equations, graphs, and tables could be perceived differently, even if they represent the same concept. The present study recognized left-turn treatment at signalized intersections as a prominent concept in traffic engineering practice and identified three associated CRs (a text-book equation, a graphical representation, and a stepwise flowchart) to design a phasing plan. Two data collection mechanisms were concurrently employed: 1) eye-tracking to analyze visual attention and document problem-solving approaches and 2) reflective clinical interviews to analyze ways of thinking and document problem-solving rationales. The problem-solving experiment was completed by twenty-four transportation engineering practitioners. Transportation engineering practitioners not only demonstrated preferences for different CRs, they also demonstrated different reasoning as to the selection of the same CR. Results of Multivariate Analysis of Variance showed that there was a statistically significant difference in visual attention based on CR. Additionally, in-vivo coding of participants' interviews identified seven distinct rationales for CR selection. Findings from this study could be employed to modify transportation engineering curricula with optimized visual CRs.

Engineering practitioners need to be competent in a variety of contexts and applications (*1*). Situated cognition theory suggests knowledge is an interaction between an individual and the resources and artifacts that are available to solve a particular problem and, correspondingly, that knowledge should be learned in the context in which it will be applied (*1*, *2*). Evidence from diverse fields and perspectives suggests that cognitive processes are affected by the external resources available to the individual. The most striking examples come from studies of situated cognition that describe: how grocery baggers manipulate their environment to optimize their task (*3*); or how individuals, tasked with placing 1/3 of 2/3 of a cup of food in a bowl, did so by measuring cups, as opposed to using formal math (*4*); or how shoppers were much more proficient in mathematics while grocery shopping than when asked to perform the same conceptual tasks in a purely mathematical context (*5*).

Similarly, previous literature showed that engineering students' responses to conceptual questions are dramatically different depending on the contextual representations (CRs) that are provided to them (*6*). CRs such as equations, graphs, and tables could be perceived differently, even if they represent the same concept (*7*). For instance, when asked about the water pressure when it flows from one size pipe to a significantly smaller one, students reasoned and responded differently when the visual representation was oriented horizontally as opposed to vertically; however, in either case, velocity and the associated fluid energy, as the main variables, were neglected (*8*). While a key feature of situated cognition research is the interaction between the individual and the CR, including features of the problem, there is limited research within engineering education in general, and within transportation engineering in particular,

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that investigates the role of CRs in individual's problem-solving approach. Additionally, CRs that are authentic to engineering practice are rarely identified. As such, the present study attempted to address this gap by first determining prominent and relevant concepts and associated CRs in transportation engineering for both academic and practitioner settings. Subsequently, design problems were developed and engineering practitioners' interaction with and interpretation of CRs during the problem-solving process were analyzed.

The decomposition of the problem-solving process often requires the application of different interviewing and monitoring techniques. In the present study, two mechanisms for data collection were concurrently employed to more holistically understand transportation engineering practitioners' interaction and reasoning while solving traffic engineering design problems: 1) eye-tracking and 2) reflective clinical interviews. Eye-tracking was employed to document gaze patterns and the visual attention of engineering practitioners and reflective clinical interviews were used to document their way of thinking. In other words, eye-tracking made it possible to determine "how" transportation engineering practitioners engaged with various CRs to solve an engineering problem, and reflective clinical interviews provided insight as to "why" transportation engineering practitioners did so.

This study is novel as it provides a variety of evidence to expand the current understanding of how engineering practitioners use representations of relevant contexts as they engage in engineering design problems. This study refers to CRs as items that can be shown on a piece of paper (e.g., graphs, tables, equations, etc.), that represent some context. It also refers to context as the meaningful association between a particular representation and an individual's ways of thinking, experience, and statement of beliefs.

## Background

The role of contexts on cognition can be captured within the framework of inscriptions and representations. Roth et al. described an inscriptional chain, which includes representations such as equations, graphs, tables, naturalistic drawings, diagrams, and photographs, that span a spectrum relating the abstract nature of language to the tangible, material world (*7*). Zhang defined "external representations" as physical symbols and physical configurations that represent knowledge and structure (*9*). An example of the role of context in problem solving comes from Reisslein et al., who noted that students exposed to both real-life situations and imagery as well as abstract problems (devoid of contextual scenarios and imagery) did better in solving problems on electrical circuits than groups of students exposed to only context or only abstract problems (*10*).

The CRs in this study encompass several of the same characteristics as inscriptions and external representations. The CRs are static in nature (rather than being dynamic), they are embedded within a tangible medium, and they are symbolic. Existing literature, particularly in the field of engineering education, provides limited explanations for the role of these representations in presenting contextual factors, despite the central role of representations within the fields of science and engineering. Detailed accounts note the central role of CRs in the everyday practice of scientists and engineers, and in referential texts used in education and research (*11–15*). The role of representations as the object of use that initiates interaction within situated contexts is a central concern within the situated cognition perspective on learning (*16*). However, only a limited amount of research within engineering education explores the role of CRs in introducing, presenting, highlighting, or noting contextual factors and the resulting effects on individuals' problem-solving processes (*17*). These studies suggest that the contexts or resources available to individuals may affect their approach to problem-solving and the cognitive domains they operate in. However, the specific features of the context that individuals pay attention to during problem solving are still largely unknown.

Researchers have proposed that eye-tracking could distinctly describe problem-solving practices and cognition (*18*, *19*). Eye-tracking refers to the application of technology to measure the activity of the human eye and is based on the "eye-mind" assumption, which suggests that eye movements correlate with attentional focus and cognitive processing (*20*, *21*). Eye-tracking measures where, when, and for how long individuals look at different features in their field of view. Common eye-tracking measures include data in the form of eye fixation locations, fixation durations, saccades (eye movements between fixation locations), and saccadic durations (*22*). Mayer has suggested that, "eye-tracking measures, such as total fixation time on relevant areas of an instructional graphic, can be successfully added to a researcher's toolbox as a way of testing hypotheses about perceptual processing during learning under different instructional methods" (*23*). Therefore, in response to the lack of knowledge regarding the influence of CRs on the problem-solving approaches of transportation engineering practitioners, this study employed an eye-tracking technique.

Concerns have been raised about relying solely on eye-tracking measures (a representation of visual attention) to interpret the cognitive processes of learners (*24*). In response to this concern, some have proposed a mixed-methods approach that would combine elements of clinical interviews with eye-tracking (*18*, *25*). It has been suggested that if problem solving tasks are followed by clinical interviews, the tasks need to be relatively short in duration because of the risk of omission or the reporting of extraneous thoughts not used (*24*). An experimental design including short problems, eye-tracking, and reflective clinical interviews will provide a robust assessment of individuals' problem-solving across different contexts.

## Research Objectives

According to the reviewed literature, gaps exist regarding the interaction of individuals and CRs, especially in engineering topics. The influence of CRs on engineering practitioners' problem-solving approach needs to be analyzed and this analysis should take place in a context that is representative of engineering practice. However, prominent concepts and associated CRs are rarely identified in engineering education in general and in transportation engineering in particular. As such, the present study employed eye-tracking and reflective clinical interviews, as two accepted methodologies in cognition research, to address the identified these gaps in literature. Specifically, the present study attempted to pursue the following research objectives:

- What is an example of a prominent concept in transportation engineering and what are the associated CRs?
- What influences the context selected by transportation engineering practitioners while solving a design problem?
- What do the fixation patterns of transportation engineering practitioners look like while solving engineering design problems?

## Method

### *Developing Concept and Context*

The overarching goal was to identify a prominent concept in transportation engineering and develop design problems that could be solved using a diverse set of CRs. To identify a concept and a variety of associated CRs, and to develop problems that leveraged both, semi-structured phone interviews were conducted with six transportation engineering practitioners. Left-turn treatments at signalized intersections was unanimously recognized as a prominent concept in transportation engineering practice. The design of a phasing plan at a signalized intersection is a complex multifaceted transportation engineering problem. Left-turn treatment is "the single most important feature that drives the development of a phase plan" at a signalized intersection (*26*). Using the information gathered from these interviews and academic and professional resources, an open-ended design problem was developed. In this problem, engineering practitioners were asked to identify the appropriate left-turn treatment (protected, permitted, protected-permitted, or split phase) on each approach of a four-leg intersection with two lanes in each approach. They were given traffic volume (left-turn, through movement, and right-turn), speed limit, sight distance, and number of left-turn-related crashes on each approach. They could make any assumptions or create any changes in geometric design and lane configuration but were asked to specify such modifications.

As shown in the literature review, various forms of CRs could be perceived differently, even if they convey the same concept. Therefore, it was important to include CRs that were formulaic in nature, tabular, and graphical because they potentially provide insight into the preferences for the kinds of representation that transportation engineering practitioners tend to choose. As such, three CRs were identified:

1) **Equation** (adopted from [*26*])

Protected or partially protected phasing should be considered whenever there is a left-turn that satisfies one of the two following criteria:

$$V_{LT} \geqslant 200 \text{ vph} \tag{1}$$

$$V_{LT} \times \left( {}^{v_o}\!/\!_{N_o} \right) \geqslant 50,000 \text{ vph} \tag{2}$$

where $V_{LT}$ is the left-turn flow rate (vehicles per hour [vph]), $v_o$ is the opposing through movement flow rate (vph) and $N_o$ is number of lanes for the opposing through movement

2) **Graph** (adopted from [*27*])

Protected or partially protected phasing should be considered based on left-turn volume, opposing speed limit, and number of opposing lanes (Figure 1).

3) **Flowchart** (adopted from [*28*])

A structured evaluation procedure to identify the least-restrictive left-turn operational mode that can meet desired operational and safety objectives (Figure 2).

The questions and associated contextual representations were piloted in a workshop setting with 45 transportation faculty. The goal was to get feedback on the overall question design, and to validate that each of the CRs was reasonably equivalent in relation to the ability to solve the problem with the CR. This effort somewhat validated the approximate equivalence of the CR. In addition, research participants used different CRs for

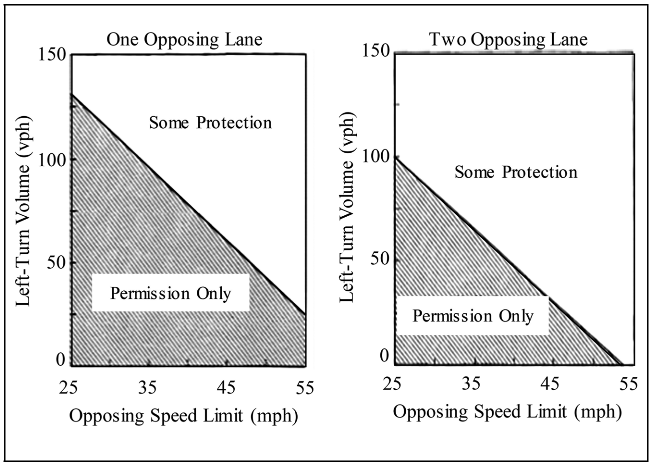

**Figure 1.** Graphical representation to determine left-turn treatment (CR #2) (*27*).

different reasons, with a somewhat equal use of each CR.

## Participants

Participants were recruited through targeted emails to local firms and agencies. Specifically, transportation engineering practitioners in both public and private sector in the Greater Portland, Oregon area were first presented with the study design and purpose, and were then asked to volunteer in this study. The final sample included a total of 24 engineering practitioners from two public agencies and two private consulting firms.

This sample is considered one of convenience, which is common in this type of qualitative research (*29*, *30*). A random sample is impossible because of challenges in getting practicing engineers to participate in such research. We did, however, take steps to get a diverse sample, and to show the data is somewhat representative of the larger population of practicing transportation engineers. The sample is diverse in the following ways: 1) the expertise of the responding transportation professionals emphasized combinations of signal timing, urban planning, and transportation design; 2) participants had a range of experience from 2 to 17 years, and the sample was approximately 40% women. Additionally, in our analysis we took steps to evaluate the representativeness of the data. Specifically, the interview data was consistent with the responses gathered from the six transportation engineering practitioners who provided feedback on the initial question design. Additionally, we observed that in the later interviews we did not find additional evidence that had not already been uncovered from the previous interviews. This is termed "saturation" in qualitative research and is a commonly used method to establish generalizability (*31*).

## Data Collection

The data collection process started after official approval from the Institutional Review Board (IRB) at Oregon State University (study number 6959). The developed problem alongside the associated CRs were organized in a single PowerPoint slide. The data collection process required a participant to sit in front of a wide computer monitor that displayed the slide. Sheets of paper and a pen were provided for each participant to document their calculations and their final solution. Participants wore eye-tracking equipment (Mobile Eye-XG platform from Applied Science Laboratories) during the entire problem-solving experiment (Figure 3*a*). During the experiment, the participants solved the problem while the researcher monitored their gaze pattern in real time. Once the participants had completed the problem, the eye-tracking equipment was removed and a reflective clinical interview was immediately conducted and audio recorded (Figure 3*b*). The questions aimed to discover the steps taken by the participant during problem-solving, which CRs were used, and why decisions were made to use those CRs. Employing a semi-structured interview protocol for reflective clinical interviews allowed researchers to ask probing questions based on their observations during the problem-solving experiment.

## Data Reduction

Data reduction was twofold. First, eye-tracking data was analyzed and second, reflective clinical interviews were coded. Eye-tracking data reduction determines the amount of time that each participant fixated on a specific CR. A single fixation was defined as when the visual gaze on a single point was maintained for a 10th of a second or longer. Eye-tracking data was manually reduced using ETAnalysis software. Each CR was considered to be an Area of Interest (AOI). Once each AOI is created, ETAnalysis calculated a wide range of visual variables including fixation counts and durations for each AOI based on the gaze patterns of the participant. Specifically, 1) Total Fixation Duration (TFD) in seconds, and 2) Average Fixation Duration (AFD) in seconds were extracted from the visual attention data. Five student transcribers spent total of 134 H to reduce eye-tracking data for the dataset.

More than 220 min of the reflective clinical interviews were transcribed via a professional transcription service. Dedoose, an online qualitative research tool was used to code and analyze interviews. The coding process was completed through in-vivo techniques where each code was based on the words of the participants (*32*). As the participants described their reasoning during problem solving, similar words were used to describe their problem-solving steps. These words became the codes

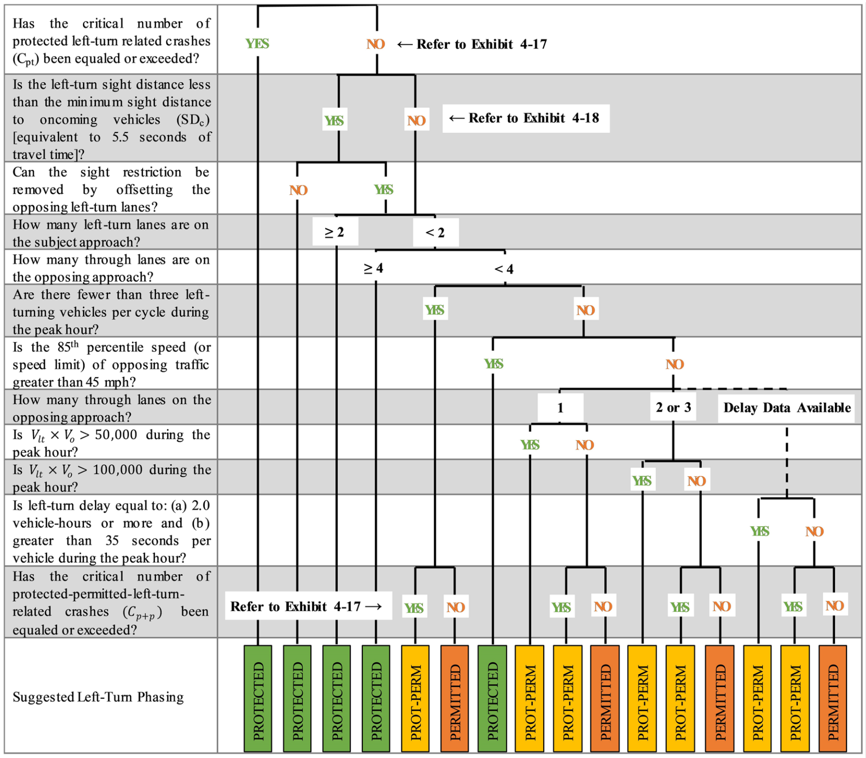

Exhibit 4-17

| Number of Left-Turn Movements on Subject Road | Period during which Crashes Are Considered (Years) | Critical Left-Turn-Related Crash Count (Crashes Per Period) | |
|---|---|---|---|
| | | When Considering Protected-Only (Cpt) | When Considering Protected-Permitted (Cp+p) |
| One | 1 | 6 | 4 |
| | 2 | 11 | 6 |
| | 3 | 14 | 7 |
| Two | 1 | 11 | 6 |
| | 2 | 18 | 9 |
| | 3 | 26 | 13 |

Exhibit 4-18

| Oncoming Traffic Speed Limit (Miles Per Hour) | Minimum Sight Distance to Oncoming Vehicles (SDc) (Feet) |
|---|---|
| 25 | 200 |
| 30 | 240 |
| 35 | 280 |
| 40 | 320 |
| 45 | 360 |
| 50 | 400 |
| 55 | 440 |
| 60 | 480 |

**Figure 2.** Flowchart representation to determine left-turn treatment (CR #3) (*28*).

**Figure 3.** Data collection process: (*a*) eye-tracking and (*b*) reflective clinical interview.

for what we describe as the participant's rationale for their preference of a specific CR. The codebook created for this study was analyzed during multiple meetings among the authors to determine consistent definitions of each code. A second coding process was completed with the developed codebook to insure proper application of those codes in each of the participants reflective interviews.

## Results

From the 24 transportation engineering practitioners who participated in this experiment, nine (37.5%) had never encountered any of the provided CRs. For the remainder of participants: four (16.7%) were only familiar with the Equation; three (12.5%) were only familiar with the Graph; three (12.5%) were only familiar with the Flowchart; two (8.3%) were familiar with both the Equation and Graph; one (4.2%) was familiar with both Equation and Flowchart; and two (8.3%) were familiar with all three CRs. To identify left-turn phasing for the given intersection, twelve participants (50.0%) solely relied upon the Flowchart, and three (12.5%) solely relied upon the Graph. However, seven participants (29.2%) used both the Flowchart and Graph, and one (4.2%) used both the Equation and Graph to reach to their final design recommendation.

Interestingly, participants not only demonstrated preferences for different CRs, they also demonstrated different reasoning as to the selection of the same CR. To understand "why" and "how" transportation engineering practitioners in this study engaged with CRs during problem-solving, data from the reflective clinical interviews and eye-tracking experiments are holistically analyzed in the following sections.

### CR Selection Rationale

One of the research objectives of the present study was to develop an understanding of CR characteristics that influence the decision of transportation engineering practitioners during problem-solving. To better understand why each participant engaged with the CRs, reflective clinical interviews were analyzed. Codes were developed from the words the engineering practitioners used to describe their problem-solving practice. Each code represents a rationale for the choice of a particular CR. The codes are defined as follows:

*Comprehensive/Detailed.* This code refers to a rationale in which a CR is selected because it provides a comprehensive/detailed approach to solve the problem. The comprehensive and detailed nature of the Flowchart caused four participants to solely rely upon this CR to solve the problem. The rationales among these participants were very similar and usually included statements such as: *"I relied more heavily upon this flowchart here because it seemed to be just a little bit more detailed than was this [Graph]."*

*Experimental Effect.* This code refers to a rationale in which a CR is selected because of its placement on the screen or by overlooking problem description or other CRs. One of the limitations of the present study is the role of experimental effect on CR choice. In fact, the problem-solving approach for three participants was affected by the positioning of CRs on the screen. For example, in response to the question, "Why did you spend quite a long time evaluating each individual CR and then moving from one to another?", one engineering practitioner indicated that: *"I didn't, at first, look to see what everything was. I kind of took it piece by piece and looked at each one in turn. Had I looked at everything beforehand, I might have gone straight to the flowchart. But … I just looked at the problem then kind of went through each of the pieces from left to right."*

*Familiarity/Comfortable.* This code refers to a rationale in which a CR is selected because it is more familiar to use and is often described as a comfortable choice. Similar to previous research, this study showed that familiarity, and the comfort that arises from it, are determinants in solving problems (*33*, *34*). Familiarity and subsequent comfort are used by four of the engineering practitioners as a description for their engagement with Flowchart as their final choice of CR. For example, when asked about their reason for choosing Flowchart, one of the participants said: *"I did look at all three of these [CRs], and I did end up using the flowchart. I think at the beginning, I spent a little bit of time looking at this method [Graph] from the Traffic Engineering Handbook … Well, it's not something I use as much so as ... Trying to think if I liked that method or not ... So, I settled on the flowchart method, I felt more comfort using the flowchart because it is typically what I use if I am just going out and building a new intersection."*

*Judgement.* This code refers to a rationale in which a CR is selected based on the participant's engineering judgment of the level of accuracy that it provides. Engineering judgement was found to be the major reason behind the choice of a CR to design a left-turn treatment at a signalized intersection. Six participants relied upon their judgement to choose a CR. In fact, the level of accuracy that was perceived by each participant from each of the CRs played a pivotal role in the engineering judgement. For example, when asked about the reason for using both the Graph and Flowchart, one participant mentioned that: *"I assumed they both were valid and accurate contexts to use and so I decided both of them ... Depending on the answer they gave, both of them could work."*

*Simplicity.* This code refers to a rationale in which a CR is selected because it requires less work and effort to solve the problem. From the 24 participants, four only selected the Graph because of the perception of reduced complexity. This was especially important for those participants who were not familiar with the provided CRs: *"I don't think I've seen the ITE [Graph] or the traffic engineering formulas [Equation] before … I started with the ITE charts [Graphs] because they're super simple."*

*Speed.* This code refers to a rationale in which a CR is selected because it provides the quickest means to solve the problem. Speed was considered a key CR preference for three participants. Here, the Graph was more frequently referred to as a quick approach: *"The graph is a quick ... for me it was used as a quick guide to determine, should I even evaluate any further, based on just two factors. Just, what's my volume? What's my speed?"*

*Stepwise.* This code refers to a rationale in which a CR is selected because it provides a step by step approach to solve the problem. For three of the participants, the Flowchart was selected as the CR because of its stepwise procedure: "*There was more decision points here and I could see if I had a different variable, how would that reset?... I wasn't really sure how to use this exactly. It's pretty straightforward, but at the same time, It's something more ...*"

*Selection Rationales vs. CRs.* Table 1 presents the co-occurrence of selection rationales and CRs. As shown in this table, participants most frequently selected the Flowchart because of the level of comprehensiveness that it provides (4/24 participants) and familiarity with this CR (four participants). The Graph was also chosen because of engineering judgement (four participants) and the simplicity of using this CR (four participants). The Equation was only referred to in two cases because of its simplicity and engineering judgement. The bottom three rows of Table 1 represent the co-occurrence of CR selection. From 24 participants, seven selected both the Flowchart and Graph and one selected both the Graph and Equation to solve the problem. The remainder of the participants relied upon a single CR to solve the problem.

**Table 1.** Co-occurrence of Selection Rationales and CRs

| Rationales | Equation | Graph | Flowchart |
|---|---|---|---|
| Comprehensive/detailed | 0 | 0 | 4 |
| Experimental effect | 0 | 2 | 3 |
| Familiarity/comfortable | 0 | 0 | 4 |
| Judgement | 1 | 4 | 3 |
| Simplicity | 1 | 4 | 0 |
| Speed | 0 | 2 | 1 |
| Stepwise | 0 | 0 | 3 |
| Flowchart | 0 | 7 | |
| Graph | 1 | | |
| Equation | | | |

*Note*: CRs = contextual representations.

### Visual Attention

According to the literature, eye-tracking can be used to describe problem-solving practices. Data from eye-tracking encompasses several different variables. Some of these variables refer to standardized values (effects neutralized over the entire sample) while others refer to the direct observed values (distinct individual variations). Since the present study attempted to capture distinct trends in the problem-solving practices of individual transportation engineering practitioners, non-standardized variables are adopted. As such, two eye-tracking performance measures were considered: 1) Total Fixation Duration (TFD) in seconds, and 2) Average Fixation Duration (AFD) in seconds. TFD refers to the total length of time for all fixations on a specific AOI and AFD refers to the mean length of time for all fixations on a specific AOI (*35*). Fixations are the period of time during which the eyes are relatively still and new information from the visual stimulus are obtained and processed (*36*). As such, when a participant is looking at each CR, and how long they look at it during each fixation (quantified by AFD), and for the entire experiment (quantified by TFD), describes how they engage with various problems and contexts. Table 2 shows mean and standard deviation values for TFD and AFD across all AOIs. In addition to CRs, participants' fixation on the problem statement (problem) and solution (outside) are included.

The data in this study was obtained through a multivariate experimental design, as two dependent variables, TFD and AFD were recorded for each individual participant. To analyze the influence of CRs on either of the visual attention measurements, Multivariate Analysis of Variance (MANOVA) was performed to test whether or not the CRs affect TFD and AFD. Additionally, to investigate the interaction of visual attention measurements, data was visualized against each of the CRs. MANOVA results showed that there was a statistically

**Table 2.** Mean (M) and Standard Deviation (SD) of Dependent Variables against Each AOI

| Dependent variable | Descriptive statistics | Problem | Equation | Graph | Flowchart | Outside |
|---|---|---|---|---|---|---|
| TFD | M | 104.86 | 23.93 | 38.25 | 135.16 | 167.89 |
| | (SD) | (59.52) | (19.25) | (23.11) | (95.74) | (211.08) |
| AFD | M | 0.28 | 0.27 | 0.25 | 0.28 | 0.35 |
| | (SD) | (0.05) | (0.08) | (0.05) | (0.05) | (0.12) |

*Note*: AOI = area of interest; TFD = total fixation duration; AFD = average fixation duration.

significant difference in visual attention based on CR use (F(10, 274) = 6.065, $p < 0.001$, Wilk's $\Lambda = 0.670$, partial $\eta^2 = 0.181$). It was found that CR use has a statistically significant effect on both TFD (F(5, 138) = 9.998, $p < 0.001$, partial $\eta^2 = 0.266$) and AFD (F(5, 138) = 4.847, $p < 0.001$, partial $\eta^2 = 0.149$).

To further investigate the influence of CRs on visual attention, TFD values are plotted against AFD values for each CR (Figure 4). Based on the recorded mean values, the distribution of visual attention by TFD and AFD can be divided into four regions which necessitates additional scrutiny. Quadrant 1 (QI) includes participants with longer TFD but shorter AFD. This group of participants spent more time fixating on each CR (compared with the mean value for the entire dataset) but their total fixation consisted of shorter gazes. The density of observations in QI for Equation, Graph, and Flowchart was 0.208, 0.125, and 0.208 respectively. Quadrant 2 (QII) includes participants with both longer TFD and AFD values. This group of participants spent more time fixating on each CR and their total fixation consisted of longer gazes. The density of observations in QII for Equation, Graph, and Flowchart was 0.208, 0.292, and 0.250 respectively. Quadrant 3 (QIII) includes participants with shorter TFD but longer AFD. This group of participants spent less time fixating on each CR but their total fixation consisted of longer gazes. The density of observations in QIII for Equation, Graph, and Flowchart was 0.125, 0.292, and 0.167 respectively. Finally, Quadrant 4 (QIV) includes participants with both shorter TFD and AFD. This group of participants spent less time fixating on each CR and their total fixation consisted of shorter gazes. The density of observations in QIV for Equation, Graph, and Flowchart was 0.458, 0.292, and 0.375 respectively.

## Discussion

Engineering practitioners made different decisions during the observed design problem-solving. Figure 4 presents the fact that engineering practitioners prefer different CRs and spend varying amounts of time fixating on each of the provided CRs. As such, a holistic understanding of problem-solving approaches among engineering practitioners requires analysis of the underlying mechanisms of their way of thinking. This could be achieved through concurrent analysis of visual attention and reflective clinical interviews.

The first observation from Figure 4 is the distribution of black dots (participants who did not select the CR as their final choice) in the quadrants of the CRs. Almost every engineering practitioner looked at all the CRs before selecting their final choice (black dots close to zero TFD represents participants who did not allocate visual attention to a CR). However, the distribution of black dots revealed that, from the participants who did not select a specific CR, 50.0% and 58.3% spent above average TFD, processing the Equation and Graph, before moving to another CR to design the final plan of left-turn treatment. On the other hand, another interesting observation is that when the Equation and Graph are selected as the final choice (anything rather than black dots), participants are more frequently placed toward shorter TFD (QIII and QIV). This could represent two distinct problem-solving approaches among engineering practitioners. The former represents the case in which participants are searching for the most appropriate method, of course in their own frame of reference, and are willing to move across the CRs as described by one of the participants: *"I looked at all of them [CRs] really. I looked at the first one [Graph] and I thought, well it looks like some protection is needed and then I walked through the flowchart to determine what I thought was the best scenario."* The latter approach represents the case in which participants select a simpler CR (predominance of triangles among CR selection rationales), again based on their own definition of simplicity, and try to design the final plan of left-turn treatment: "*It's [Graph] very easy to correlate one with the other and feed it into the question, versus the other items require some type of calculation. I don't think I felt prepared or felt like I had the time to go through any rigorous calculations. I used what was simplest and most efficient.*"

Variations in the AFD and TFD values (as shown in Table 2) and quadrants' density for each of the CRs (as shown in Figure 4) shed further light on the problem-solving approach of practicing engineers. Participants maintained a more consistent visual attention while using

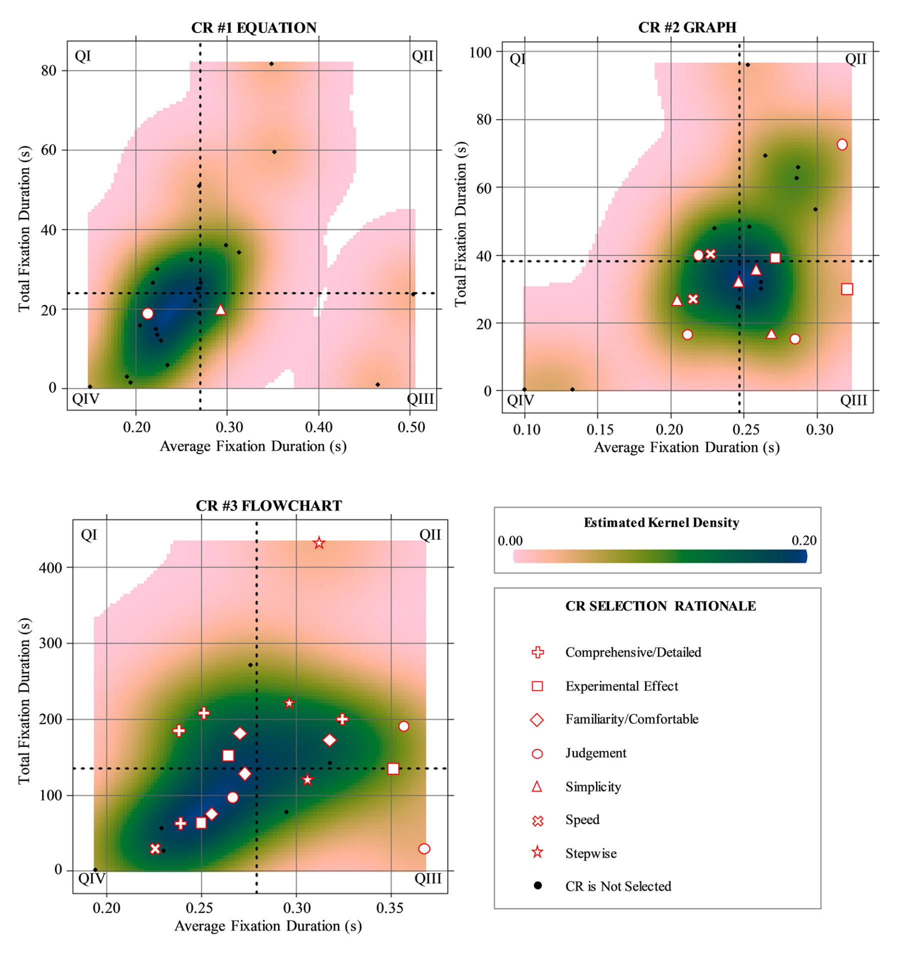

**Figure 4.** Distribution of visual attention across CRs and based on selected rationale.

the Graph. This is well demonstrated by the smaller range and standard deviation of TFD values and higher circular density concentrated around the mean AFD and TFD (dark green and blue), in addition to the fact that density values showed participants are almost equally distributed in the quadrants of Graph. On the other hand, participants are very different in their visual attention when it comes to interactions with the Flowchart. Considerably higher standard deviation and visual attention that is skewed toward shorter AFD values (QI and QIV) confirm the inconsistent approach in using the Flowchart. The question is now why engineering practitioners employ these two CRs differently. The Graph is chosen based on rationales that are inherently very similar. Simplicity, speed, and judgement (accuracy) are often mentioned as reasons to select the Graph. However, the Flowchart is chosen based on distinct reasoning. Comprehensiveness of the Flowchart and participants' familiarity (comfort) with its procedure are frequently mentioned as reasons to select the Flowchart. While the former rationales created a consistent narrative for the problem-solving practice, the latter ones caused inconsistency. For example, when one of the participants who used both the Graph and Flowchart was asked about their CR selection rationale, it was stated that: "*It's simple [Graph]. There's only two variables to look at. Only two numbers. It did help me, actually, look at this and say, okay am I gonna have it two easy numbers. If they tell me that I need some protection, then look at the more complicated. The tree [Flowchart] which involves more input*."

Another observation relates the visual attention with specific rationales for the entire CRs. Looking at the visual attention shows that working with a CR that is perceived to be simpler (triangles in Figure 4) resulted in shorter total fixations as this group of participants are all positioned within QIII and QIV. Familiarity (diamonds in Figure 4) was found to be an important rationale behind the choice of a CR for several engineering practitioners in this study. Distribution of visual attention shows that while this group of participants are observed in three of the four quadrants (QI, QII, and QIV), they are shifted toward shorter AFD values, meaning that they had shorter fixations each time that they fixated on the familiar CR. Experimental effect (squares in Figure 4) was previously mentioned as a limiting factor, causing some participants to select a CR based on the PowerPoint slide layout. While this group of participants are observed in all four quadrants, they typically had shorter TFD values. As might be anticipated, the group of participants who chose Flowchart because of its comprehensive (plus signs in Figure 4) and stepwise (stars in Figure 4) procedure, were more frequently observed in QI and QII. In fact, they had longer TFD values as they spent more time going through all the details and steps of the Flowchart. Opposite to this group, those who chose a CR because of its fast procedure (crosses in Figure 4) were shifted toward QIV, with both shorter TFD and AFD values. Finally, no consistent pattern was observed for that group of participants who chose a CR based on their engineering judgement (circles in Figure 4).

## Summary and Conclusion

There is a gap in knowledge about prominent concepts and contexts in civil engineering in general, and in transportation engineering in particular. Much of engineering education still relies upon the teaching and presentation of concepts in an academic context rather than an applied engineering context. Additionally, no one has yet analyzed how transportation engineering practitioners interact with CRs, including features of a problem while solving traffic engineering design problems. This study attempted to first identify an example of a prominent concept and its associated CRs in transportation engineering, and then to evaluate transportation engineering practitioners problem-solving approach. Left-turn treatment at signalized intersection was identified as a prominent concept and three distinct formats of presentation, Equation, Graph, and Flowchart were identified as associated CRs. Eye-tracking was used to evaluate "how" transportation engineering practitioners engaged with various CRs to solve a signal phasing problem and reflective clinical interviews provided insight as to "why" transportation engineering practitioners did so.

The findings of the current study emphasized the importance of rationale and how it can impact the problem-solving approach of transportation engineering practitioners. The results showed that there was a statistically significant difference in visual attention based on the selected CR. Transportation engineering practitioners employed CRs in distinct ways and described their problem-solving decision in different rationales. For example, the Graph was selected because of similar rationales and therefore, visual attention was equally distributed, while the Flowchart was selected on distinguishable rationales and participants were observed all over the map. Additionally, one group of participants spent quite a long time processing all the details and steps of the Flowchart, while another group chose the Graph as a simple and fast method to design final left-turn phasing plan.

Seven distinct rationales were identified and described in detail. However, one concern rises from familiarity with the provided CRs. Signal phasing in general, and left-turn treatments in particular, are foundational topics in traffic and transportation engineering. As such, transportation engineering practitioners should be familiar with the available resources in these areas or at least have encountered some of the CRs. Nonetheless, it was found that 9 of 24 of transportation engineering practitioners in this study had never encountered any of the CRs and only 2 of 24 were familiar with all three CRs. This finding suggests a revision of traffic and transportation engineering course content may be warranted to equip the future workforce of transportation engineering practitioners with the most up-to-date knowledge on signal phasing and left-turn treatments.

Because of the close connection between the eyes and the brain, visual attention is an important measure of cognitive activity (*35*). Notably, it is during fixations that one receives information from the visual stimulus that they are processing. Therefore, results from this research could be utilized to modify transportation engineering curriculum with optimized visual CRs. Longer AFD could represent more difficult tasks that require higher levels of interpretation skills. It was found that a conventional graphical representation caused the lowest AFD and created the most consistent pattern in visual attention. On the other hand, a more comprehensive approach, the Flowchart, was found to have the highest AFD with a large degree of uncertainty in the observed pattern of visual attention. While this could break the balance in favor of graphical representations, it should be noted that transportation engineering practitioners more frequently relied upon the Flowchart as it represented a detailed procedure to solve an engineering design problem. As such, CRs that are inherently detailed, comprehensive, and stepwise but at the same time include graphical representations could be a good choice to use in a transportation engineering classroom.

### Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. 1463769.

## Author Contributions

The authors confirm contribution to the paper as follows—study conception and design: SB and DSH; concept and context development: MGA and DSH; data collection: MGA; analysis and interpretation of visual attention: MGA and DSH; in-vivo coding: SLG and SB; analysis and interpretation of clinical reflective interviews: MGA and SLG; draft manuscript preparation: MGA, SLG, SB, and DSH. All authors reviewed the results and approved the final version of the manuscript.

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*The Standing Committee on Transportation Education and Training (ABG20) peer-reviewed this paper (19-02211).*