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Traffic Signal System Misconceptions across Three Cohorts: Novice Students, Expert Students, and Practicing Engineers

Mr. Mohammad Rabiul Islam, Oregon State University
Dr. David S Hurwitz, Oregon State University

Dr. David S. Hurwitz is an assistant professor of transportation engineering in the School of Civil and Construction Engineering at Oregon State University. David conducts research in the areas of transportation user behavior, traffic control, transportation safety, driving & bicycling simulation, and engineering education. In particular Dr. Hurwitz is interested in the consideration of user behavior in the design and innovation of transportation systems. David teaches graduate and undergraduate classes covering topics such as; Highway Engineering, Traffic Operations, Isolated Signalized Intersections, and Driving Simulation. Additionally, Dr. Hurwitz serves as an executive committee member of the Institute of Transportation Engineer's Traffic Engineering Council and Education Council, and as a member of the Transportation Research Board's Simulation and Measurement of Vehicle and Operator Performance committee (AND30), and Traffic Control Devices Committee (AHB50).

Dr. Shane A. Brown P.E., Oregon State University

Identifying Traffic Signal System Misconceptions of Students and Practicing Engineers to Develop Traffic Signal Concept Questions

Abstract

Theories of situated knowledge and research evidence suggest that students are not prepared for the engineering workforce upon graduation from engineering programs. Concept inventory results from diverse fields suggest that students do not understand fundamental engineering, mathematics, and science concepts. These two concerns may result from different knowledge deficiencies; one from lack of conceptual understanding and the other from lack of applied knowledge. The research goals of this paper are to identify misconceptions related to traffic signal operations and design in novice and expert engineering students and practicing engineering and to examine and attempt to explain the patterns in misconceptions across the three cohorts. Results indicate three patterns (decreasing, increasing, and no change) in the presence of misconceptions across the three cohorts considered in this study (novice students, expert students, and practicing engineers). The traditional model of learning explains the decreasing pattern of misconception. The theory suggests improved understanding with additional instruction and student time on task. The pattern of increasing misconception appeared for concepts that were particularly complex and confounded, where practicing engineers produced much more complex answers that were mostly correct, but made leaps and speculations not yet proven in the literature. Misconception frequencies that stayed the same tended to include topics that do not have required national standards or that are buried in automated processes. The process of identifying and documenting misconceptions that exist across these cohorts is a necessary step in the development of data driven curriculum. An example of a conceptual exercise developed from four misconceptions in the clinical interviews is also demonstrated.

Project Introduction

Transportation safety is traditionally concerned with the minimization of crash frequency and/or severity on our Nation's roadways. These crashes are influenced by three system components: the driver, the vehicle, and the built environment. Civil engineers have the unique ability to directly manipulate the built environment, all the while needing to understand the associated human factors and vehicle capabilities. In 2004, "NCHRP Report 500 Volume 12: A Guide for Reducing Collisions at Signalized Intersections" suggested that the use of traffic control and operational improvements have the greatest likelihood to improve safety at signalized intersections [1].

A large body of research has shown that many graduating students do not possess understanding of fundamental engineering concepts [2]. Confounding the lack of concern over the lack of conceptual understanding are differences between how academics and engineering professionals think about and apply fundamental engineering concepts. Situated cognition experts contend that knowledge only exists in context and has very limited meaning and usefulness when taught out of context [3, 4]. An urgent educational need exists to better integrate engineering students within the context of engineering practice and to develop, implement, and assess curricular materials that represent this integration, including high quality assessment instruments. No concept inventory instruments currently exist in transportation engineering, and no existing engineering concept inventory (CI) instruments have been validated in engineering practice. The lack of situated or contextual curricular materials integrating conceptual understanding and practice impedes students' abilities to be productive and innovative engineers.

Project Goals

The objective of this research effort is to synthesize early career engineering professionals' and students' mental representations or models of traffic signal systems and use this knowledge to develop a concept inventory in traffic signal operations that is relevant to engineering practice. Conducting fundamental engineering education research on student and practitioner ways of knowing is a critical and often overlooked first step in curriculum and assessment design. As such, having an engineering design relevant traffic signal operations concept inventory (TSCI) will provide explicit evidence of what is important for students to know, how much they know about these important concepts, and how and where to focus transportation engineering design courses.

The specific aims of the research include the following elements:

1. To determine engineering student and practicing engineer misconceptions related to traffic signal operation and design,
2. To explain patterns in misconceptions across novice student, expert student, and practicing engineer categories, and
3. To demonstrate data driven curriculum design through the application of misconceptions to conceptual exercises.

Project Activities and Outcomes

The planned activities for this study were focused around achieving the specific aims listed in the previous section. The major project activities include the following:

Interviews and Misconceptions

The overall methodologies utilized for identifying the misconceptions are shown in Figure 1, which includes the process of developing concepts for the study using a Modified Delphi Method, interview protocol development, interview methodology, and data analysis procedures.

a. Selecting Core Concepts:
   The fundamental concepts of traffic signal operations were identified through an iterative modified Delphi process involving 14 senior transportation engineering professionals and 16 engineering faculty from across the country who have been involved both in teaching and doing research in the area of traffic signal operations. Determination of fundamental concepts included the individual development of a list of core concepts and a webinar to discuss, debate, and build consensus on the final concepts.

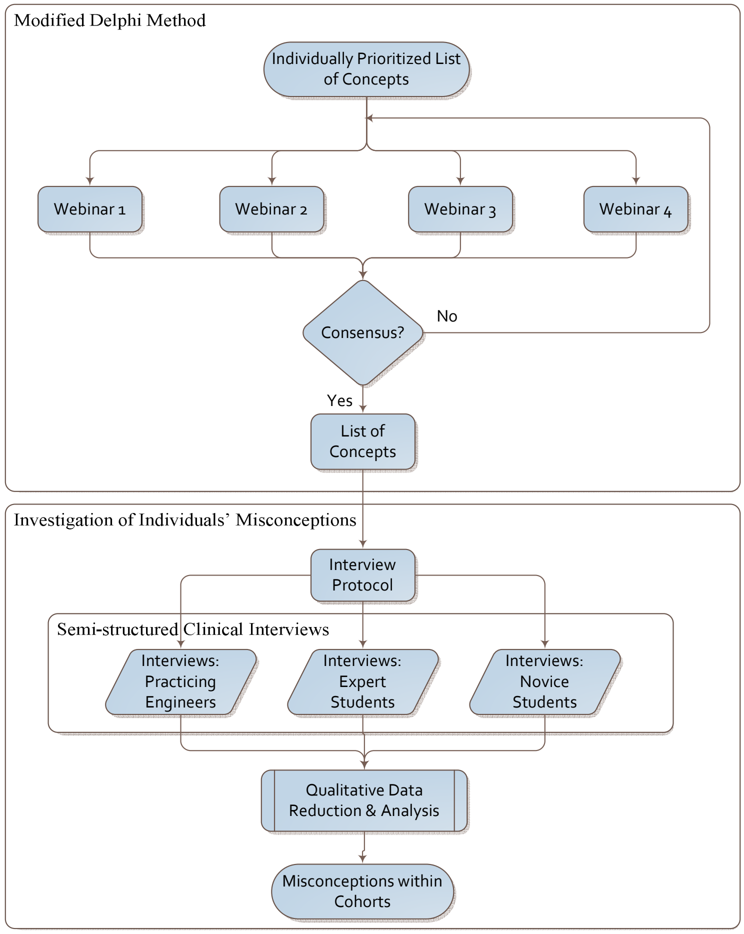


Figure 1 Flow Chart of Delphi Method and Clinical Interviews

b. Protocol Development and Implementation:
A semi-structured interview protocol was developed (one for the novice students and one for the expert students and early career practicing engineers) using the selected concepts of traffic signal warrants, signal timing, traffic signal phasing, and timing parameters. The reason for producing a different interview protocol using more common and accessible terminology for novice students was their lack of technical knowledge related to the content. However, care was taken to focus questions on the same underlying concepts in both protocols, in order to generate meaningful responses on the same conceptual content from all three cohorts. The interview protocol consisted of 28 core questions that are asked of all participants, and 13 probing questions that are asked selectively based on interview responses.

c. Clinical Interviews:
An open-ended style of interview was used in this study to elicit interview participant's understandings of core concepts. The clinical interview was focused on uncovering an individual's way of thinking about an idea, based on the assumption that individuals have unique features of their understanding. Interview participants consisted of three cohorts: practicing engineers, expert students, and novice students. The first cohort included a total of 24 practicing engineers from Spokane, WA, 12 from Portland, OR, and 2 from Boise, ID.

Both private and public sector practicing engineers were interviewed, with 1 to 28 years of experience. The second cohort included 13 expert students from one public university. Expert students had taken at least one graduate level course in traffic engineering. The third cohort consisted of 17 novice students from another public university in a different state. Novice students had either completed the introduction to transportation engineering course or were currently enrolled in the course when interviewed. Interviews lasted approximately 45-60 minutes for practicing engineers and expert students and approximately 30 minutes for the novice students.

d. Qualitative Data Reduction and Identifying Misconceptions:
In total, 48 hours of clinical interviews were conducted and transcribed, resulting in 975 pages of interview data for qualitative analysis. Transcribed interview data were coded and analyzed using the qualitative data analysis and research software, *Atlas TI* [5]. Interviews were coded for the correctness of responses with the goal of identifying misconceptions. Misconceptions were considered to be anything respondents verbalized that was incorrect and detailed enough to be understood. A set of 58 codes for misconceptions and associated definitions were used to analyze the interview transcriptions. A typical code included two components: the general topic and the description of the misconception. For example, "*Cycle Length-Coordinated-Concept-misconception-It has to be the same for all intersections*." In this example, "Cycle Length-Coordinated-Concept-misconception" describes that the interviewee had a misconception about the cycle length of coordinated traffic signals and the phrase, "it has to be the same for all intersections" provides additional details of the misconception. This is a misconception because there are cases in a coordinated corridor where, due to large differences in volumes at subsequent signals, cycle lengths may be different, as long as they are an even multiplier of one another. Responses of "I don't know" or "it could be [answer]" were not considered misconceptions. Frequencies of misconceptions in each cohort were determined, and all misconceptions that were present in at least 30% of the participants from one of the three cohorts were included in the results.

e. Identifying Patterns of Misconceptions:
The analysis of the interview transcripts led to three noticeable trends in misconceptions when comparing the categories across cohorts for each concept:

- <u>Novice Students Highest – Expert Students Middle – Practicing Engineers Lowest</u>
  There is a decreasing trend in the percentage of misconceptions with increasing expertise for the concepts of approach speed and cycle length within the data set. One common misconception regarding approach speed was, "Approach speed is determined by taking an average of the speeds empirically observed in the field." Eleven out of 17 novice students, one out of 13 graduate students, and none of the 24 practicing engineers were found to have this misconception. When approach speed is considered as the operating speed of the road, it is commonly determined by calculating the 85^{th} percentile from spot speed study data collected in the field [6]. Novice students are not familiar with this process and are more prone to propose taking the average, which is a common descriptive statistic used to measure the central tendency of data sets in numerous classes and alternative contexts that these students have participated in. On the other hand, expert students are exposed to the mechanics of calculating an 85^{th} percentile speed as well as its

theoretical justification. Practicing engineers frequently refer to various engineering manuals and design guides where 85th percentile speed is commonly used.

- Practicing Engineers Highest - Expert Students Middle – Novice Students Lowest
  Practicing engineers indicated several misconceptions for the concepts of minimum green time and passage time with a minimal evidence of misconceptions among novice and expert students. It was evident from the novice student responses that they were not particularly familiar with the minimum green time concept, even from their everyday driving experiences. Two students said that a very short green duration is a rare event, and that might result from the preemption caused by emergency vehicles. Two other students said that it might happen due to a software or hardware malfunction. On the other hand, expert students seem to understand the concept very well, as most of them worked with this concept in graduate course work; only one out of thirteen students appeared to show any confusion with the concept. The most noticeable discrepancy was found in the practicing engineer cohort; four out of 24 were able to define the concept accurately, but their perception of this concept was confounded by other performance measures at the intersection, such as queue length and delay. Traffic engineers deal with these two measures of effectiveness (MOEs) more frequently than any other MOEs. They often use simulation software to predict the performance of transportation systems. These applications allow engineers to input timing parameters, such as the minimum green time, and in response to those variables, and numerous others, the system outputs MOEs such as average delay and queue length. It is possible that this operational procedure has resulted in a way of thinking for some traffic engineers that tend to make a connection between the minimum green time and those MOEs.

- No Change of Misconception Across Cohorts
  The trend of cohorts being approximately equal in the frequency of misconceptions was found in the concepts of vehicle volume, red clearance interval, effective green time, and gaps. Considering the high rate of misconceptions for all of the cohorts, it is possible that these are "embedded concepts." As such, it is possible that they are not used directly for traffic signal timing; therefore, practicing engineers may not have a need to fully understand these concepts. One such example is effective green time. This concept is not as explicit as cycle length or maximum green time and is not a timing parameter that engineers use as a direct input to the traffic controller or traffic simulation software, and because the implications often cannot be mapped directly to signal timing issues, engineers seem to have difficulty recalling and understanding the concept. The fact that effective green time is related to a number of other concepts, such as start-up lost time, green duration, cycle length, and clearance lost time, contributes to the lack of understanding or the existence of misconceptions about this concept across all three cohorts.

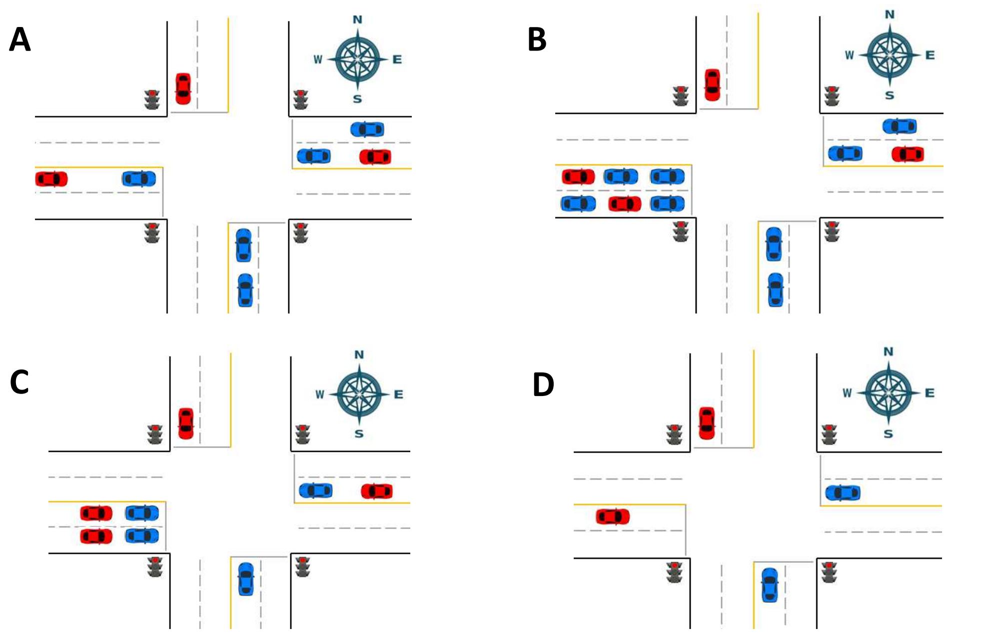
Curricular Materials and Concept Inventory Development

In order to demonstrate how clinical interview data, and in particular the identified misconceptions, can be applied to improve traffic signal education, a series of conceptual questions were developed. The objectives were to help students and young practitioners to better understand traffic signal fundamentals and to help educators to better teach those principals.

When interview data is used to construct conceptual exercises, it is important to correctly select meaningful student misconceptions. Misconceptions, in this sense, are not just wrong answers. They are wrong answers founded in strong student reasoning and are traditionally difficult to correct, even when students are presented with contradictory evidence.

The conceptual exercises include Concept Inventory (CI) questions and Ranking Tasks. CI questions are multiple choice exam questions with one correct answer and multiple “distracters” (misconceptions that are determined from research on student and practitioner understanding through interviews and pilot testing) and are designed to assess students’ conceptual understanding of a particular topic. Ranking tasks constitute another category of conceptual exercise. In a ranking task, students are asked to order a sequence of typically three to six items based on a particular characteristic. Often the items are pictures or figures, and the task is intended to be completed without the use of calculations. The task can be made more difficult by including extraneous information and presenting the items in a variety of contexts. An example ranking task is included below (Figure 2).

The following figures show typical four-leg signalized intersections with different traffic volumes.
Rank the figures based on the duration of the red clearance interval (all-red time) required for the east-bound traffic signal phase before displaying green to the north-south direction of traffic, from the longest to the shortest. Assume identical lane configuration and intersection geometry in all four cases, and 35 mph posted speed limit on all four approaches and the same design vehicle at each intersection.



Longest ________ ________ ________ ________ Shortest
Or, the red clearance interval should be same __________
Or, the information is not adequate to determine the red clearance interval __________
How sure are you of your ranking? (circle one)
Basically Guessed Sure Very Sure
1 2 3 4 5 6 7 8 9 10

Figure 2 Example Ranking Task

In order to confirm that the developed traffic signal concept questions are of marked predictive value, it is critical to validate the questions. The developed questions and answer keys were reviewed multiple times by academics and experienced traffic engineering professionals before sending out to engineering schools across the nation for validation. The inventory will be validated through two general approaches; test-retest reliability and item analysis. Test-retest reliability will determine if scores are consistent across different randomly selected portions of the exam. The item analysis will help determine if individual distractors are valid or not, based on the frequency they are selected. The test-retest reliability of the TSCI will be determined by administering the exam to the same set of student respondents during two different times. To minimize the potential for a "practice effect", the inventories will be given at least one month apart. Additionally, to avoid learning effects, the TSCI will not be given during the same time traffic signal concepts are being taught. A high degree of reliability would result from the test scores being approximately the same for both test times.

Project Impact

The outcomes of research efforts are a prioritized list of concepts of traffic signal operations that engineering faculty and senior engineering professionals believe are important; a synthesis of students' and early career engineering professionals' understanding of traffic signals, resulting in a draft set of distractors for each TSCI question; a taxonomy of differences in knowledge of students and early career engineering professionals related to traffic signals; national dissemination of a valid and reliable traffic signal operations CI a database of student performance on the TSCI in the classroom; and a framework for developing situated concept inventories.

Concept inventories in transportation engineering, and more specifically traffic signal engineering, do not exist. This study is significant, because it fundamentally advances the field by identifying differences in conceptual understanding between practicing engineers and students and develops a concept inventory instrument incorporating practitioner understandings. Data collected from practicing engineers and students can be used for several vital purposes that include curriculum development, such as inquiry based conceptual exercises [7, 8] and assessments that complement CI questions, such as open-ended design problems, both of which will be situated in engineering thinking and design. The methodologies developed can be applied to the development of future engineering concept inventories situated in engineering practice. Moreover, these results can be used to attempt to bridge the gap between academia and the workplace.

Accomplishments

As of now, the project accomplishments included the development of curriculum materials in the form of conceptual exercises and solutions, refereed conference and journal publications, and poster and podium presentations regarding the project findings. Table 1 describes the question type and topic area of the 94 conceptual exercises and one page solutions developed for the project.

Table 1. Developed Conceptual Exercises and Solutions

Question Type:	Topic Area:	Number of Questions Developed (with answers):
Concept inventory questions	Actuated signal	5
	Coordinated signal	4
	Cycle length	5
	Effective green time	5
	Red clearance interval	5
	Yellow change interval	5
Ranking tasks	Actuated signal	5
	Coordinated signal	5
	Cycle length	4
	Effective green time	5
	Red clearance interval	5
	Yellow change interval	5
Interpretation questions	Actuated signal	5
	Coordinated signal	4
	Cycle length	5
	Effective green time	5
	Red clearance interval	8
	Yellow change interval	9
	Total	**94**

Additionally, aspects of the project were presented in the NSF Awardees poster session at the ASEE Annual Conference & Exposition in 2013, and will be presented in a podium session at the Transportation Research Board's annual meeting in 2014. These presentations have resulted in the following publications:

- **Hurwitz, D.**, Brown, S., Islam, M., Daratha, K., & Kyte, M. (Accepted 10/2013). *Traffic Signal System Misconceptions across Three Cohorts: Novice Students, Expert Students, and Practicing Engineers*. Transportation Research Record: Journal of the Transportation Research Board (Paper 14-2234).
- **Hurwitz, D.**, Brown, S., Islam, M., & Daratha, K. (2013*) Mental Models of Students and Practitioners in the Development of an Authentic Assessment Instrument for Traffic Signal Engineering*. 120th ASEE Annual Conference & Exposition Conference Compendium.

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