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RESEARCH ARTICLE

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Integrated engineering education through design activities: A signal phase module design case study for traffic engineering course

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Abstract

This article presents an integrated educational module for undergraduate traffic engineering at the microscale level. When dealing with a complex transportation system, the education program should cultivate students' acquisition of both in-depth traffic specialization and breadth of engineering knowledge. For the educational instruction of the signal phase design, this article presents an integrated design that includes several engineering subjects: signal phase design, circuits and electronics, and object-oriented programming (OOP). Due to the lengthy evolution of signal phase design and the high-end industrial standards for this issue, this well-structured problem requires an instructional design to adopt a worked example that integrates varied engineering domains. The integrated design session is intended to deliver education through designing a miniature signal controller while creating an immersive situation and encouraging social teamwork. Feedback from participating students has been positive, indicating the achievement of the planned learning objectives and better mastery of engineering practices.

KEYWORDS

integrated design, OOP (object-oriented programming), traffic engineering education, worked example

1 | INTRODUCTION

Reports from studies seeking to determine how engineering education should be delivered to students to prepare them to become engineers have focused on analytic skills, mathematics, and science. This is shown in Figure 1 within the review of engineering education's evolution over approximately one century [7].

Education for the transportation profession needs to address not only the challenges posed by the roadway

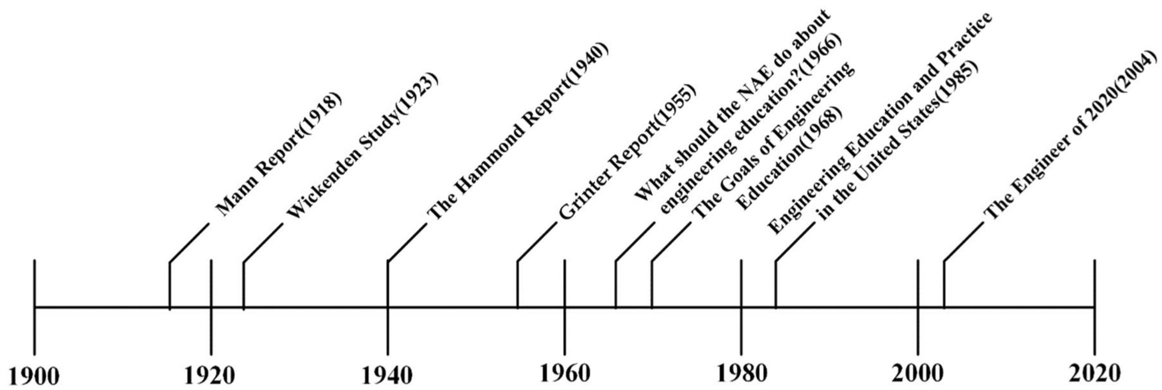

FIGURE 1 Evolution of engineering education [7].

systems but also the emerging waves of vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) technology evolution [6, 18, 45]. The new generation of transportation professionals needs both in-depth specialization and breadth of transportation knowledge [38]. Specialization is important as it provides the intellectual rigor needed to pursue innovation and technological insights in this challenging and dynamic field. The breadth of transportation knowledge is central to the education process, developing an awareness of and sensitivity to a broad set of transportation issues that are intertwined with almost every aspect of the real world. The transportation professional must know the alternative views of professionals from different specializations and other stakeholders with varied primary interests. For future transportation systems, the following key technological functions are required: the ability to sense system conditions on transportation networks, the ability to communicate, process, and display large amounts of information , and the availability to process this information to improve systems performance. Therefore, the transportation profession should address the transportation system by taking a holistic view of its components. Due to the extensive interactions between transport systems and society, the transportation profession needs to be able to deal with intrainstitutional and interinstitutional relationships that support the development and deployment of transportation programs through which engineering elites can effectively deliver societal leadership.

In traffic engineering, interdisciplinary education needs to elaborate the holistic view (i.e., the extensive interactions between transport systems and society). Elements need to include, among others, legal issues, health and safety, environmental concerns, and landscaping and planning, with public consultations also taken into consideration. In addition to organizing the teaching of knowledge and skills, numerous studies highlight the interdisciplinary and integrative capabilities needed in the education of future engineers [39]. If an interdisciplinary approach is to be adopted in engineering students' projects, it is crucial to coordinate between teachers, students, and the curriculum [13]. According to research conducted by Vasquez et al. [8], an interdisciplinary approach should focus on content and practices from two or more disciplines connected through a common theme or problem. Engineering education should cultivate students who are good at communication, organization, management, creative and innovative thinking, and value personal qualities [22]. Therefore, a good project begins by stimulating students' interest in the course, with students no longer regarded as passive receivers of knowledge [5]. Students are allowed to explore new ideas and feel excited and enthusiastic about realizing them. At the same time, they are confident they can complete projects within the specified time [13]. However, curriculum integration does not solely place different disciplines into one class or unit, but pays attention to the relationships between related disciplines and real-world problems, as well as the relationships with other disciplines [32]. The curriculum should include projects that involve applied learning that meets the teaching purpose. These projects can promote students' in-depth participation in useful applications, practical problems, and interdisciplinary work [46]. To engage in this interdisciplinary study, various disciplines must be integrated to deliver solutions for complex problems. However, despite this need, the curriculum in many engineering schools is limited when it comes to cultivating interdisciplinary problem-solving and skill-building [14].

The science, technology, engineering, and mathematics (STEM) method has been proposed for engineering education. When faced with accelerating industrialization, STEM teaching must adapt to the requirements of modern industry, simultaneously providing theoretical knowledge and practical skills [44]. In basing curriculum design on the conceive, design, implement, and operate (CDIO) method, the belief is that interdisciplinary courses should include varied professions with interconnections and that the introduction of professional skills generates a synergistic relationship [10]. This approach to designing, operating, and coordinating undergraduate engineering education programs has the objective of producing work-ready graduates who have mastered the essential professional and technical skills when they begin their fledging careers.

An integrated engineering education module is specifically designed for traffic engineering course to facilitate inter-domain learning across various engineering subjects by providing bridging activities. It provides opportunities for engineering students to establish a learning program integrated with traffic engineering, electronic engineering, and software engineering on in-field practical engineering problems. Integrated engineering education offers students the opportunity to engage in real-world design and practical engineering experiences throughout their studies [25]. In this way, the participants acquire the necessary inter-domain engineering and professional skills. This article proposes a new approach to address the need for integrated learning in transportation design case study through instructional design and learning environment establishment. The case study also delivers a whole package of materials for instruction purposes, including ID, demonstration kit design, and driver code.

The traffic industry, correlated as it is with other sectors, intrinsically requires inter-domain knowledge and skills. These domain shells are inconsistent with the trend toward the integration of technologies, with engineering problems not always restricted within these artificial boundaries. Traffic engineering issues have fuzzy boundaries in practice, with the integrated design process encompassing varied engineering areas. The current traffic engineering course consists of two major components by the nature of the traffic stream: uninterrupted flow and interrupted flow. The design of the signal phase at signalized intersections is the core component for the latter one. The design of the signal phase at isolated intersections is conventional and mature for common traffic engineering practices. The more complex systems, such as the corridor-wide green wave scheme and system-wide optimization scheme, had been developed for a long time. For instance, Sydney Coordinated Adaptive Traffic System (SCAT) and Split Cycle Offset Optimisation Technique (SCOOT) were developed and spread to major international cities worldwide [20]. After a long time of evolution, the theory and the field practice of signal systems require high magnitudes of reliability and security for busy and conflicting traffic at intersections under outdoor conditions. Although the industry has progressed to achieve remarkable applications in the field, higher education delivers a few case studies involving signal phase design [19, 21, 35]. But most of them are limited by engineering domains. This work proposes an integrated design case study to fill two gaps when addressing the issue of signal phase design.

- Develop employable skills for traffic industrial professions.

  The transportation systems require a breadth of knowledge and skills, for example, communication and presentation.
- Enhance trans-domain engineering insights.

Since the case study is a component of the traffic engineering course, the term domain instead of discipline represents a smaller study scale. Students can look at the same theme from the perspectives of different individual domains. However, transportation systems require future professionals to cross interrelated domain boundaries to create a holistic approach. Trans-domain requires a collaboration theme between domains to create a cohesive solution.

The following section describes the methodology for ID. It analyzes the context of a traffic engineering problem to select a suitable ID model. This section regarding teaching activity design transforms the selected abstract model into realistic activities. Detailed instructions are presented in the section of the case study. It demonstrates thorough instructional elements that can be a cookbook for lecturing. A survey was designed to evaluate the case study, and the results were presented, followed by a discussion of the students' feedback and performance. Finally, the conclusion remarks deliver the key findings and tips for applications, and two group reports are attached in the appendices.

2 | METHODOLOGY

The complex and rich-content case study requires instructors to consider the whole project thoroughly. Initially, the intrinsic nature of this issue should be clarified. Then, a selected instruction design (ID) has to be shortlisted from the established models. Finally, the proposed instructional model needs to consider the case content for adaptivity.

2.1 | Well structured versus ill structured

First, it is critical to analyze the nature of this case study based on its definition, contents, and possible extensions.

TABLE 1 Characteristics of well-structured problems [36].

1. There is a definite criterion for testing any proposed solution and a mechanizable process for applying the criterion.
2. There is at least one problem space which can be represented by the initial problem state, the goal state, and all other states that may be reached, or considered, in the course of attempting a solution to the problem.
3. Attainable state changes (legal moves) can be represented in a problem space, as transitions from given states to the states directly attainable from them. But considerable moves, whether legal or not, can also be represented—that is, all transitions from one considerable state to another.
4. Any knowledge that the problem solver can acquire about the problem can be represented in one or more problem spaces.
5. If the actual problem involves acting on the external world, then the definition of state changes and of the effects upon the state of applying any operator reflect with complete accuracy in one or more problem spaces the laws (laws of nature) that govern the external world.
6. All of these conditions hold in the strong sense that the basic processes postulated acquire only practicable amounts of computation, and the information postulated is effectively available to the processes—that is, available with the help of only practicable amounts of search.

The definition of a well-structured problem is shown in Table 1. Thus, the signal phase design is a well-structured problem in terms of clear problem context, prescribed methodology, and convergent answers.

2.2 | Instructional design

The transportation system components require a new pedagogy, with technical insights, integrated systems, and interorganizational coordination essential to cultivate a new generation of transportation professionals. In the current study, the independent projects develop self-motivation, analysis skills, insight and creativity, technical confidence, and autonomy. To meet the dynamic requirements of the traffic engineering profession, an innovative engineering methodology is proposed to develop a trans-domain case study for a traffic engineering course. A proposed case study, consisting of phase design and controller, adopts open-source hardware and software. The case study demands the traffic survey, signal phase design, signal phase optimization, and phase design implementation. Thus, the case study designed by open-source hardware and software enables the development feature of modularity for rapid development, implementation, and testing.

For the instructional design of this case study, this well-structured problem is in a constrained problem context with convergent methods that engage the application of a limited boundary of engineering principles within well-defined parameters [17]. There are four common instructional strategies, namely, practice, worked examples, analogical comparison, and self-explanation [31]. The instructional methods for improving problem-solving have studied well-structured problems such as those found in mathematics and science learning, while heavy use of worked examples was hypothesized to lead to more effective processing by reducing cognitive load [17]. In addition, this learning mode is preferred by novices, and it is an effective way of learning [42]. When learning to solve well-structured problems, worked examples of how to solve the problems are typically provided as a primary form of instruction. Worked examples are instructional devices that typically model the process for solving the problem [2]. Thus, the worked example is an appropriate ID for undergraduates learning the well-established contents of traffic signal phase design.

When using the worked example, the article adopts Gick's model of problem-solving strategies, representation construction, schema activation, and heuristic search [15], shown in Figure 2. These elements are incorporated into the following instructional design.

To deliver a whole component of engineering theory and practice, students are provided with the task or problem formulation, the procedure or step-by-step process for solving the problem, and the solution. The worked example of signal phase design is step-by-step illustrations of the process required to complete a task or solve a problem. The worked example should break down complex solutions into smaller meaningful solution elements, present multiple examples in multiple modalities for each kind of problem, emphasize the conceptual structure of the problem, vary formats within problem types, and reveal the deep structure of the problem. With the demonstration of the working procedure, the instructors assist students by constructing a representation to understand the problem by focusing on the goal, the constraints, and background information. This construction may activate a schema if the problem is familiar.

When using worked examples for instruction, the instructor should focus on learning from worked examples in earlier stages of skill acquisition and facilitate the transition to problem-solving in later stages.

Schemas provide knowledge structures for encoding and interpreting particular experiences, greatly reducing the heuristic search required for solution-seeking.

Using faded worked examples addresses this effect by structuring the learners' transition from studying the worked example to learning with problem-solving. The

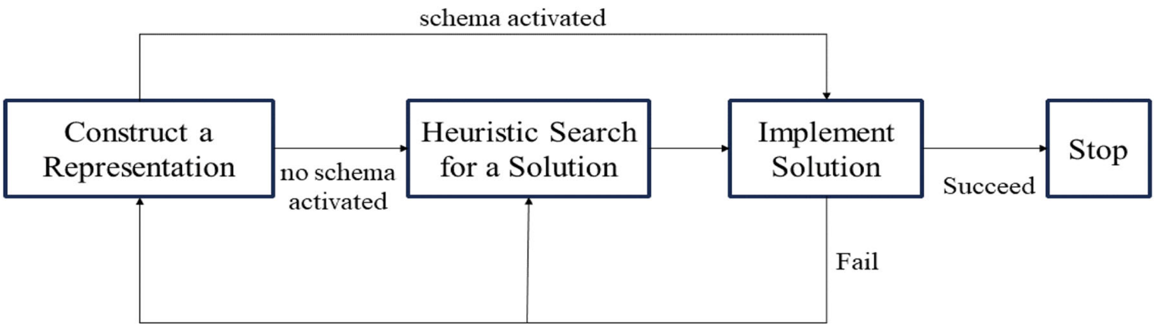

FIGURE 2 Problem-solving stages [15].

faded worked examples encourage search practice based on discovery learning principles. If a student can invoke a schema, it is an active process in which a particular experience is matched to a schema that best suits that experience. Otherwise, the heuristic search is expected to place a considerable load on cognitive loading [41].

It is effective to fade out successively worked solution steps in worked examples and trigger learners' self-explanations of the reasons for the given solution steps [30]. According to self-explanation activity supplemented with instructional explanations (SEASITE) principles proposed by Renkl [28], self-explanations are provided by learners and mainly directed to themselves. They contain information that is not directly given in the learning materials and that refers to solution steps and the reasons for them. Thus, the learning workload is shifted to students gradually.

The intention is that these design problems would enable students to develop their innovation skill sets while combining fundamental concepts and engineering principles across subjects [40]. The social and material context of the learning is first established by the instructor with the above-mentioned fundamental components delivered by lecture presentations. Students are surrounded by tools with their purpose being to lead to presentations that can help guide their work. The use of tools also leads to collaboration among engineers, aided by presentations, that decisively reinvent engineering cognition and practice [26]. The case study also delivers a process of reversal engineering. The lecturer starts the program by analyzing a ready signal controller system to identify the system's components and their relationships, followed by creating the system representations at a higher level of abstraction. The discovery-based learning research suggests that worked examples can establish engaged and constructive learning experiences [1].

Social interaction is also a critical component of situated learning—learners actively participate in a "community of practice" that embodies certain behaviors and the codes of conduct to be acquired [16]. As novices move from the outer ring of the community to its center, they become more active and engaged within the culture and, hence, assume the role of seasoned experts. The below-mentioned case study realizes this direction using a hand-manufactured traffic controller that becomes a pivot to interconnect various engineering domains. It starts with a demonstration of the existing signal controller. It finalizes with a self-explanation demonstration of each team's own solution, including signal phase design and its application on self-manufactured hardware.

3 | TEACHING ACTIVITY DESIGN

3.1 | General information

At Beijing Jiaotong University, the transportation engineering course is organized on two levels. One level is the Bachelor of Science (BS) degree awarded by the School of Traffic and Transportation, while the other is the postgraduate Master of Science (MS) degree. Although both programs educate transportation engineers, they have different objectives, duration, and curricula.

3.2 | Current program at university

The transportation subjects in the current program are offered by the School of Traffic and Transportation. Of approximately 300 students who take the introductory courses each year, around 50–60 undergraduates with a traffic engineering major will continue with the traffic engineering course. This program emphasizes traffic engineering and planning methodology. The course's major subjects discuss transport system characteristics, for example, transport modeling, traffic signal timing, assessment of various side-effects, such as accidents, noise, air pollution, and energy consumption, and transport project evaluation and decision-making. Students can specialize in various traffic subjects according to their individual motivations. Courses offered at the specialized level are road traffic engineering, urban public transport, and intelligent transportation systems.

The three independently taught parallel components, traffic phase design, electronics, and object-oriented programming (OOP), comprise peer-to-peer discussions, hand-manufacturing experiences, laboratory experiments, and technical demonstrations that create an active teaching and learning atmosphere. Compared with other programs, this program can offer a more holistic engineering knowledge structure than the hands-on traffic signal experiences gained in summer school [19]. It also delivers a more comprehensive solution not limited to an electronic controller design to a large extent [35].

To demonstrate interactions between components and to reinforce the concepts taught, instructors have developed a series of design activities. The teaching objectives of these activities comprise:

(1) Motivate students' inquisitiveness when experiencing a typical traffic engineering problem in the field;
(2) Form a good foundation of certain traffic engineering concepts and develop a comprehensive knowledge of theories in relevant subjects;
(3) Advance design and manual manufacturing dexterity through open-source hardware development;
(4) Enhance social skills via a community learning approach and peer instruction [3, 24]; and
(5) Establish confidence in students to undertake trans-domain projects that involve both traffic engineering and electrical components [14].

The instruction team comprises three members: a lecturer and two teaching assistants. The lecturer is responsible for and delivers three components by presentation using slides, a miniature signal controller, and video. The two teaching assistants undertake auxiliary tasks, for example, electronic parts procurement, collection of assignments, and so on. Moreover, the team aims to inspire students' learning motivation and encourage participation. Hence, formal lectures and the typical timetable of classroom courses are to be replaced by a fused module with a completion deadline project mixed with a combination of lectures, tutorials, informal group discussions, and formal question/answer (Q/A) sessions with instructors.

The case study is delivered in three sessions. Each session comprises six consecutive hours comprising the introduction, demonstration, and team discussion and practice. Each session starts with a presentation of engineering knowledge with a video demonstration and a miniature signal controller model. Informal group discussions are arranged spontaneously to create an atmosphere supportive of actions and reactions. Formal Q/A sessions are held as problems are encountered and appropriately solved. The purposes of these sessions are as follows: (1) to ensure most student participants can capture the progress of the delivery of the correlated sequential components of the project and (2) to establish the varied participation roles. Students work on independent projects and with peers on team projects, with the latter developing teamwork and leadership skills. Students acquire technical knowledge, practical skills, and successful experiences as projects evolve and are completed.

4 | CASE STUDY: A DESIGN PROJECT ON SIGNAL TIMING AT A FOUR-LEG INTERSECTION

4.1 | Case study introduction

Signal timing has always been an important topic for transportation engineering curricula [33, 43]. Hence, this case study has a clear border for the phase time design of a regular isolated signalized intersection. It is expected that the student team can finish the traffic survey, signal phase design, and implementation using a self-manufactured controller. A group assignment, including a report, driver code, and controller, should present a detailed traffic survey, the phase design optimization process, and the driver code's design. The case study is a miniature example of an ordinary signal phase optimization project.

The worked examples method is a cognitive learning strategy that involves providing learners with step-by-step solutions to problems or tasks. The procedure for using worked examples in this case study is as follows. The case study selects a simple example representing learners' problems or tasks. A case study of the T-intersection is presented initially, incorporating layout diagrams, graphs of the signal controller, and a working example of a signal controller. The example is a general case in practice, and it can be developed into different variations and gradually evolved into a more complex and common case, namely, cross intersection. The scope and contents are clearly defined, and the learning objectives are elaborated. A fully worked-out solution to the problem is provided and explained step by step in detail. Moreover, the instructor should point out the key traffic engineering concepts, phase design principles, and strategies used in the solution, emphasizing the progressive development from signal phase design, circuit manufacturing, and driver program to the final implementation. Over time, the lecturer gradually shifts the responsibility to the undergraduates to work through problems independently. The lecturer also encourages undergraduates to verbally or mentally explain the steps and concepts to themselves as they follow the example in the varied interactions. This self-explanation presentation helps to deepen understanding and retention, and it is an essential component of the learning assessment.

4.2 | Case study flow chart

This case study consists of three major self-contained stages. In the first stage, student groups are requested to complete the phase timing scheme and assemble the prototype using simulation software. In the second stage, students are required to build a signal timing scheme based on a given four-leg intersection or T-intersection that includes pedestrian movements. The instructor should specifically prohibit student groups from selecting an intersection with a one-way road, as the case study requires general field practice and comparable complexity in the design project for the purposes of evaluation. In addition to gaining an understanding of signal timing concepts, students must carry out a field investigation of an intersection. Students then need to assemble a circuit prototype that simulates the operation of the signal timing scheme. Finally, in the third stage, student groups need to compile and test driver programming for the signal controller prototype. This case study starts with a traffic problem but is not merely a bounded traffic domain. Thus, trans-domain teaching is applied to come across domains using common issues that thread through different components. To deliver a well-rounded solution for this multifaceted problem, the trans-domain requires close collaborations among domains to create a cohesive component. The project can be accomplished in these steps, as illustrated in Figure 3.

4.2.1 | Task 1: Establish a signal timing scheme

Although the initial example is the T-intersection as planned, the lecturer has to prepare a full mode of signalized intersection. The signal timing scheme is for an isolated fixed-timing intersection. According to the results of a field investigation close to the campus conducted by students, the cycle length is 171 s (s), with a yellow interval length of 3 s (s) or 4 s (s) for the clearance (all red) interval of the given intersection.

The signal timing scheme includes four phases for this four-leg intersection. The first phase is composed of a through movement with a permitted right turn at the major street, followed by the second phase consisting of two protected left-turn movements in the north–south direction. Likewise, the latter two phases control the east–west direction movements. The vehicle movements are demonstrated in Figure 4, with details of the scheme's time allocation shown in Figure 5 and Table 2.

The project uses Synchro simulation software, with the simulation needing to input geometric design data and traffic volumes according to the field survey results. The width of a single vehicle lane is set as 3.5 meters (m), with details of the simulation process shown in Figure 6.

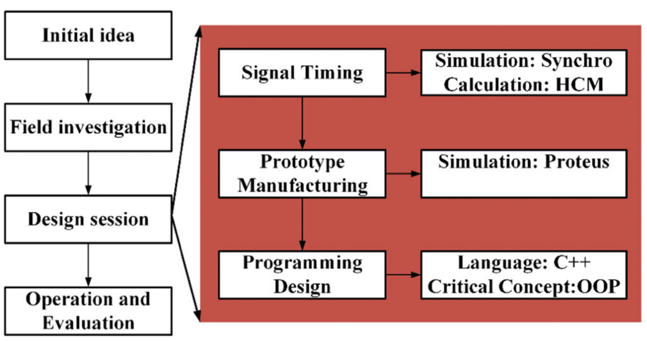

FIGURE 3 Case study flow chart. HCM, highway capacity manual; OOP, object-oriented programming.

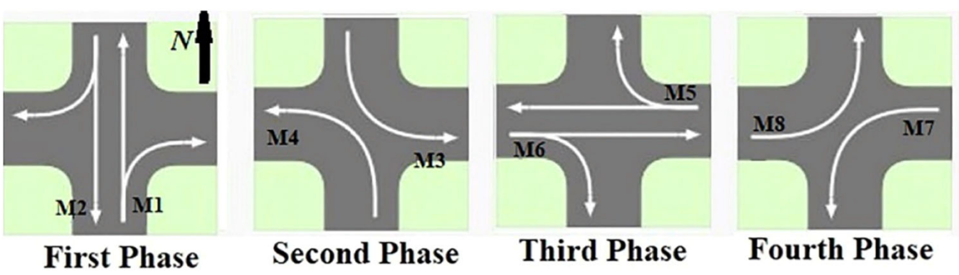

FIGURE 4 Vehicle movements with four-phase intersection signal. M, vehicle movements; P, pedestrian movements.

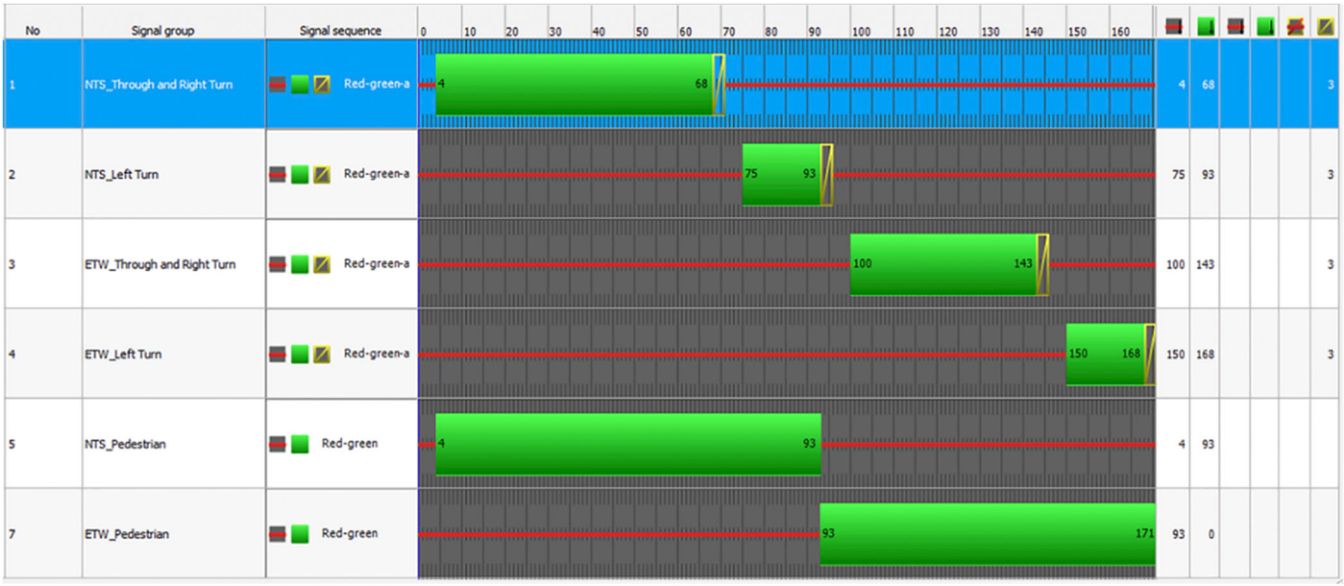

FIGURE 5 Details of signal phase timing scheme.

TABLE 2 Signal timing scheme time allocation.

	Green lights(s)	Yellow lights(s)	Red lights(s)	Pedestrian movements (light/length in N–S[a])	Pedestrian movements (light/length in E–W[b])
First phase (N–S[a])	64	3	4	Green/71 s	Red/71 s
Second phase (N–S[a])	18	3	4	Green/25 s	Red/25 s
Third phase (E–W[b])	43	3	4	Red/50 s	Green/50 s
Fourth phase (E–W[b])	18	3	4	Red/25 s	Green/25 s

Abbreviation: s, seconds.

[a]Represents north–south direction.

[b]Represents east–west direction.

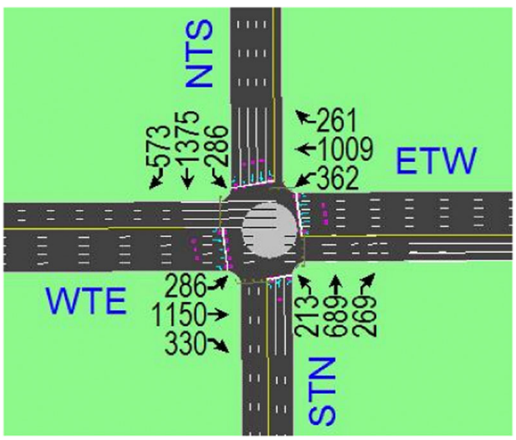

FIGURE 6 Simulation process. ETW, direction from east to west; NTS, direction from north to south; STN, direction from south to north; WTE, direction from west to east.

TABLE 3 Results of performance evaluation.

Index	
Control type	Pretimed
Maximum volume/capacity (V/C) ratio	3.28
Intersection signal delay	259.6
Intersection capacity utilization	93.3%
Intersection level of service (LOS)	F

The performance evaluation results of the process illustrated in Figure 5 can be assessed as shown in Table 3. The intersection level of service (LOS) is F, with intersection capacity utilization at over 90%. All the data above suggest that the current signal timing scheme is not suitable for the intersection. Therefore, it is necessary to optimize the intersection signal timing to achieve a higher LOS.

4.2.2 | Task 2: Manufacture a prototype of the intersection signal system

Unlike conventional rapid prototyping in software engineering, the case study has to simplify the controller for educational purposes and set a technical scope to meet the requirements of the mature traffic control industry with high security and reliability standards to a large extent. The prototype of the intersection signal system consists of various colored light-emitting diodes (LEDs), a microcontroller unit (MCU), resistances, and wires, as shown in Figure 7. The presented representation is an industrial controller by McCain using diagrams and video. The existing system consists of a sophisticated power supply for all-weather conditions, a programmable unit, and a relay system to control groups of signal lights, as shown in Figure 8a. A miniature example is also fully prepared by the lecturer to demonstrate the process of externalized representation establishment. The manufactured miniature one has been simplified to focus on the core functions of the signal controller. The protection of the power supply is omitted, and the MCU controls traffic lights without the relay system. Two legs of an LED are connected to the ground and to an output interface of the MCU, which contains 52 output interfaces via wires, as shown in Figure 8b. A resistance is added to this circuit to smooth out the current with an individual circuit, as displayed in Figure 9. The prototype simulates a four-leg intersection that can guide vehicle and pedestrian flow in four directions. Each leg of the intersection contains one vehicular signal group and one pedestrian signal group. The three different colored LEDs are taken as

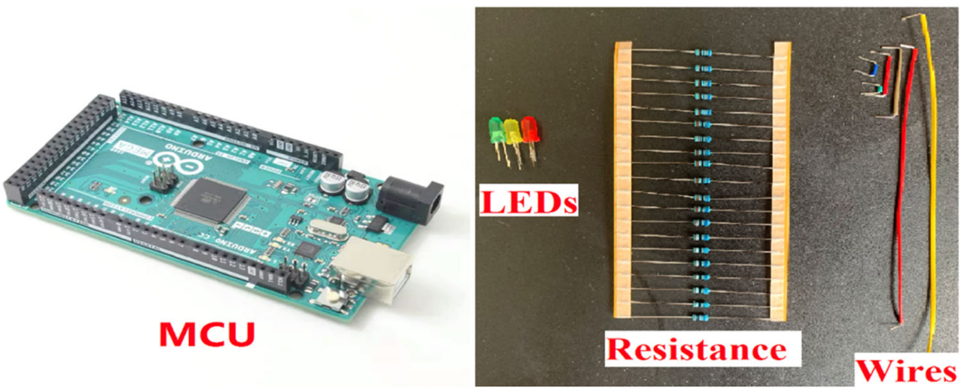

FIGURE 7 Components of prototype. LED, light-emitting diode; MCU, micro-controller unit.

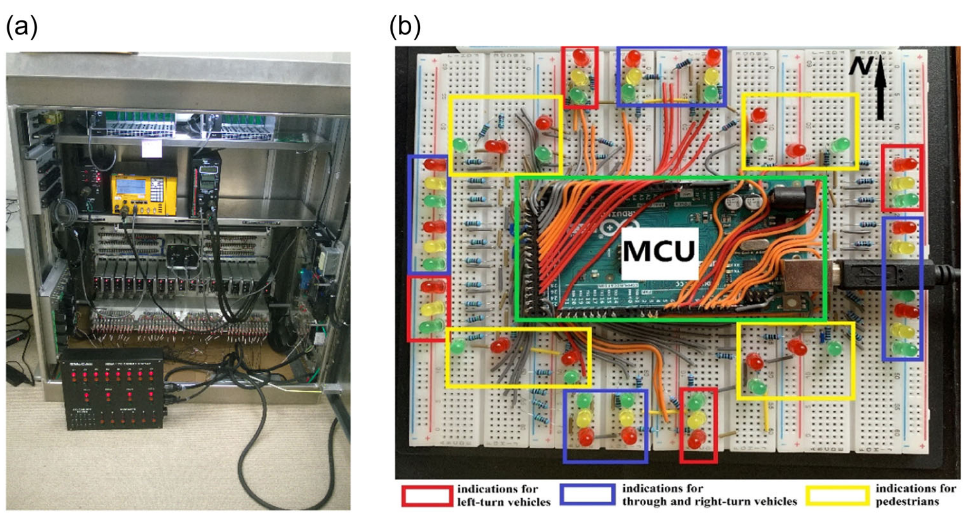

FIGURE 8 Prototype circuit of the four-leg intersection (video for demonstration is available upon request). MCU, micro-controller unit.

one group of traffic signals that can control one vehicular movement. The pedestrian signal group consists of one green light and one red light. All groups are connected to the MCU in the same way as previously described.

One of the most important objectives of the entire project is to manufacture the prototype and check its functionality. The circuit wiring is complex, as illustrated in Figure 8. To avoid or identify errors that may happen in the manufacturing process, it is crucial to simulate the model in advance. Proteus is used to simulate the circuit wiring and display the operational performance of a compiled MCU program. Drawing a circuit diagram is necessary for this process to check the feasibility of the new prototype and for manufacturing quality assurance. Figure 10 is the circuit diagram demonstrated by Proteus.

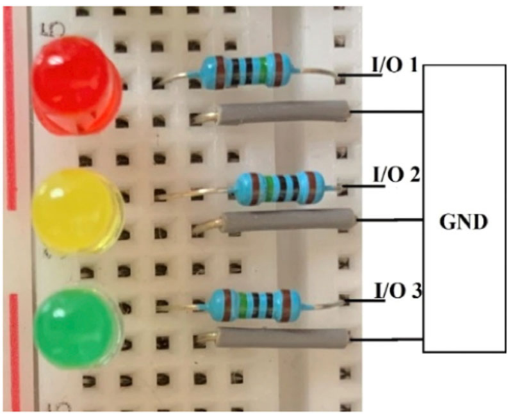

FIGURE 9 Individual signal group circuit. GND, signal ground; I/O, input/output.

4.2.3 | Task 3: Compile and test driver programming

OOP is a critical concept for computer science [9]. In this case study, OOP is a vital educational element, with the concept and its applications essential for the new generation of transportation professionals. OOP aims to implement real-world entities, such as encapsulation, inheritance, and polymorphism [37]. The Arduino unit uses the compiled C++ program to control the MCU hardware. Learning C++ in a class is the building block that leads to OOP. This is a user-defined data type, which holds its own data and member functions and can be accessed and used by creating an instance of that class.

The isolated signal controller hardware programming is a natural analogy to the OOP concept. Encapsulation is defined as the binding together of

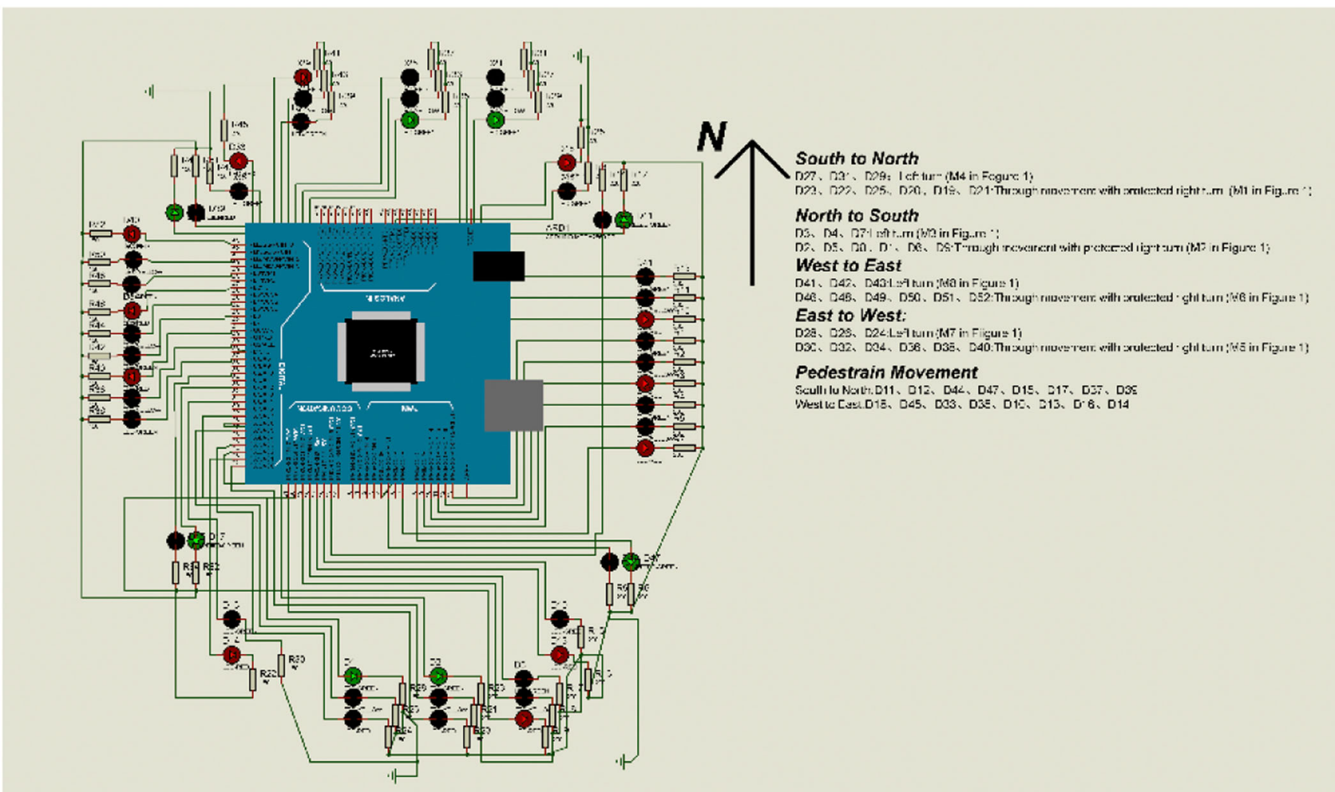

FIGURE 10 Simulated circuit diagram of the prototype (video for demonstration is available upon request).

the data and functions under a single unit which controls the length of the signal phase and movement configurations for each individual phase. Therefore, in the signal controller example, the signal control class consists of several phase control functions and data members to enable its functionality, as described next. To use the MCU to control multiple groups of lights, each light of a movement is designed to associate with a fixed pin of the MCU, in accordance with the wiring shown in Figure 10. The polymorphism feature can be demonstrated by this example of the cross-intersection class. A function named "move ()" that enables green movements can be overloaded by changing the number of movements, that is, one movement for a T-intersection or two movements for a T-intersection. A "phase ()" function is afterward established to enable simultaneous movements within one phase and to define the phase time length. A function named "check ()" can be called on to interlock conflicting movements within one phase for the safe application of the signal phase scheme.

Designing a signal timing system involves building an independent timing function library that includes both variables and MCU functions. The student groups need to write an.h file and a. cpp file. For example, for the T_YE function:

Set the length of the yellow interval, identified as 3 s (s) in the project.

Choose two LEDS, that is, NTSYE and NTSYE1 in this example.

Invoke the digitalWrite function to control the states of the LEDS:

```
Void PEDESTRIAN::T_YE(int NTSYE, int NTSYE1){
    digitalWrite(NTSYE, HIGH);
    digitalWrite(NTSYE1, HIGH);
    delay(3000);
    digitalWrite(NTSYE, LOW);
    digitalWrite(NTSYE1, LOW);
}
```

Private class:

Variables: The variables define signal groups by different directions, with a single colored LED corresponding to a specific variable.

For through movements:

NTSGR,NTSYE,NTSRED,STNGR,STNYE,STNRED, WTEGR,WTEYE,WTERED,ETWGR,

ETWYE,ETWRED;For left-turn movements:

NTSGR1,NTSYE1,NTSRED1,STNGR1,STNYE1,STNRED1, WTEGR1,WTEYE1,WTERED1,ETWGR1, ETWYE1,ETWRED1;

For right-turn movements:

(Continues)

NTSGR2,NTSYE2,NTSRED2,STNGR2,STNYE2,STNRED2,W-TEGR2,WTEYE2,WTERED2,ETWGR2,ETWYE2, ETWRED2;

For pedestrian movements:

STNGR3,STNGR4,STNRED3,STNRED4,NTSGR3,NTSGR4,NTS-RED3,NTSRED4,WTEGR3,WTEGR4,

WTERED3,WTERED4,ETWGR3,ETWGR4,ETWRE-D3,ETWRED4;

which are as follows:

NTS: Direction from north to south

STN: Direction from south to north

ETW: Direction from east to west

WTE: Direction from west to east

GR: Green LED of a signal group

YE: Yellow LED of a signal group

RED: Red LED of a signal group

Functions:

T_YE (): Light up two chosen yellow LEDs for the length of the yellow interval;

T_RED (): Control states of two chosen red LEDs;

AT_RED (): Control states of three chosen red LEDs;

F_RED (): Control states of pedestrian signal groups in one direction;

MOVE (): Control states of all green movements for either a phase of through and right-turn movements or a phase of left-turn movements: this can be reloaded for a varied number of movements.

Public class:

PIN_MODE: Initialize all pins of the MCU to the output signal;

All_RED (): Light up all red LEDs for red clearance;

PHASE (int TIME, int Legs): Define various traffic movements in a specific phase and its time length.

Check (): Interlocking function to avoid conflicting traffic flow in a phase.

The cross-intersection class is presented using a Unified Modeling Language (UML) diagram, as shown in Figure 11.

Similarly, a T-intersection circuit prototype can be manufactured. Based on the schema proposed, student groups can transfer it to other layouts of intersection signal systems. And it can be reproduced with a few revisions to assemble a greenwave corridor.

4.3 | Case study: Classroom lectures

To implement this trans-domain education method, a traffic engineering course was delivered at Beijing Jiaotong University. The course enrolled 60 third-year undergraduates. After relief from coronavirus disease 2019 (COVID-19) pandemic restrictions in September 2020, the course was made available through classroom lectures, and the case study was delivered in intensive

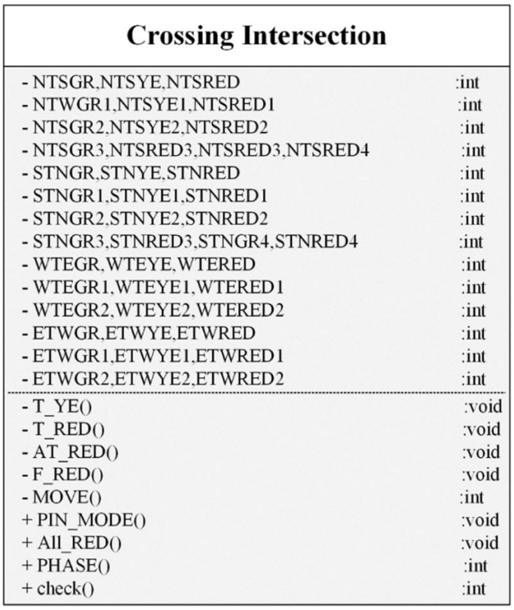

FIGURE 11 Unified Modeling Language (UML) diagram of class design. +Public; -Private; #Protected; ~Package (source code can be accessed upon request).

TABLE 4 Three-session intensive teaching time plan.

Session	Time (hours)
Phase design	Session 1: (6)
Field survey	
Circuit manufacturing	Session 2: (6)
Code design	Session 3: (6)
Debugging	

mode, as shown in Table 4. The whole class was divided into five to seven-member groups to tackle this group assignment. The target was to use the self-made signal controller prototypes to present an optimized phase time design based on trans-domain knowledge through teamwork, peer instruction, and instructor supervision. A questionnaire was designed to estimate the learning outcomes immediately after the completion of this practical session.

The practical activity was mainly carried out by combining classroom teaching, field investigation, and code debugging. To complete each component, the cooperation of the director and all students was required:

4.3.1 | Step 1: Traffic signal phase design

Each student group created a corresponding signal timing plan based on students' theoretical knowledge of signal timing and the results of their field investigations. The research site, a T-intersection outside the west gate of Beijing Jiaotong University, is shown in Figure 12 below.

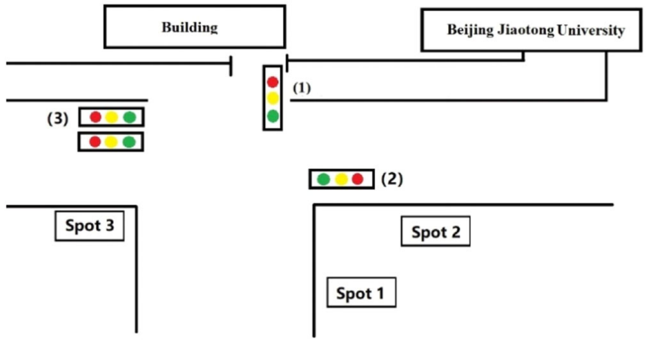

FIGURE 12 Field investigation site.

After students learned the basic concepts and developed their signal phase design knowledge, each group discussed and drafted its own work plan designed to mobilize their enthusiasm for their learning motivation. Their main task was to access basic information about the intersection over 1 h, including the cycle, operating time of each leg's signal, vehicle flow, and pedestrian flow. This information would help them to design and optimize the intersection signal phases.

4.3.2 | Step 2: Electronic circuits and micro-controller unit (MCU)

Step 2 in this component was designed to take up to 6 h. The main teaching content provided by the instructor introduced students to the MCU and related circuit technology. As an introductory example, a simple project of lighting up an LED was developed based on the MCU, so students could learn the circuit, MCU functions, and physical operation, as shown in Figures 13 and 14. Based on the results of the project and the previous field survey, all groups then attempted to design a corresponding T-junction circuit diagram and to wire up the circuits simultaneously.

4.3.3 | Step 3: Driving programming design

The most important subtask was applying the concept of OOP, as illustrated in Figure 15. Students were mainly focused on preparing a library that included various methods for formulating a signal timing plan. In the

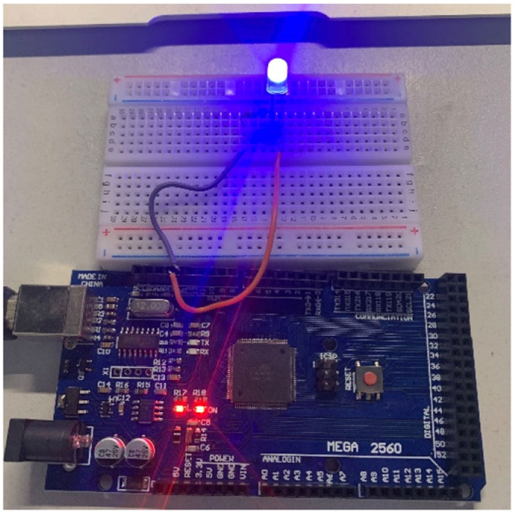

FIGURE 13 Presentation example of circuit wiring.

FIGURE 14 Intragroup discussion and manufacture.

process of compiling and debugging the program, students encountered different problems. Finally, most groups were able to finish Steps 3 and 4 on time, with most of the primitive prototypes manufactured by student groups both functional and operational.

4.3.4 | Step 4: Prototype manufacture

The prototype manufacturing step was carried out simultaneously with Step 3. Group members collaborated to compile the driving programming and design circuits. Meanwhile, in both intergroup and intragroup discussions, each group could communicate its difficulties, leading to the delivery of feasible suggestions. The example of the controller is illustrated in Figure 16.

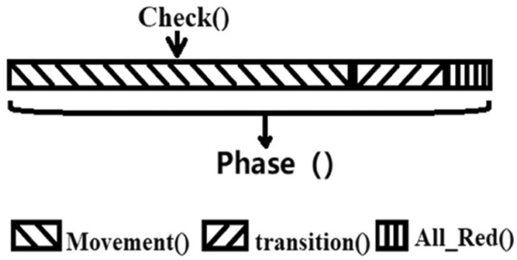

FIGURE 15 Object-oriented programming (OOP)-based functions presentation.

Meanwhile, the instructor and tutors were available for timely consulting. As mentioned in the previous section, most groups completed the prototype development within the 18-h intensive teaching session. The case study covers multiple dimensions, so it is sophisticated enough to avoid plagiarism. It is not viable to memorize solutions without deepening understanding when the undergraduates are working on this project. The prototypes completed by all groups are shown in Figure 17.

The teaching sessions were basically completed after four steps, but students' practical activities were not limited to the case study. When students are introduced to a new task, the worked example is more effective than having students solve problems. On the one hand, the instructor should encourage them to attempt more complex tasks, cross intersections and even irregular intersections, to develop proficiency and automaticity [29]. On the other hand, the teams are under necessary peer pressure when interacting with other teams to solve this complex problem. They could make further improvements to the primitive prototypes. For example, they could continue manufacturing a cross-intersection prototype, as previously illustrated in Figure 8. They were asked to hand in their innovative prototypes and to make presentations to demonstrate self-explanation for course assessments, as illustrated in Figure 18. The procedure of improvements and following products are the self-evidence of actively learning to extract and digest underlying principles of signal phase design.

The case study starts with the contents of traffic engineering knowledge in the abstract. The case study extends to the field practices. The students gain insights into the operation of traffic lights by compiling the driver code. Through the teaching plan shown in Table 3, the engaging students are gradually exposed to a larger extent of engineering knowledge. Moreover, the learning of these correlated components can lead to synergy effects. Thus, the students are inspired or even forced to learn the existing worked example and extracurricular knowledge. The role of the students is shifting from passive receivers to active learners. Interestingly, due to Intergroup competition, most

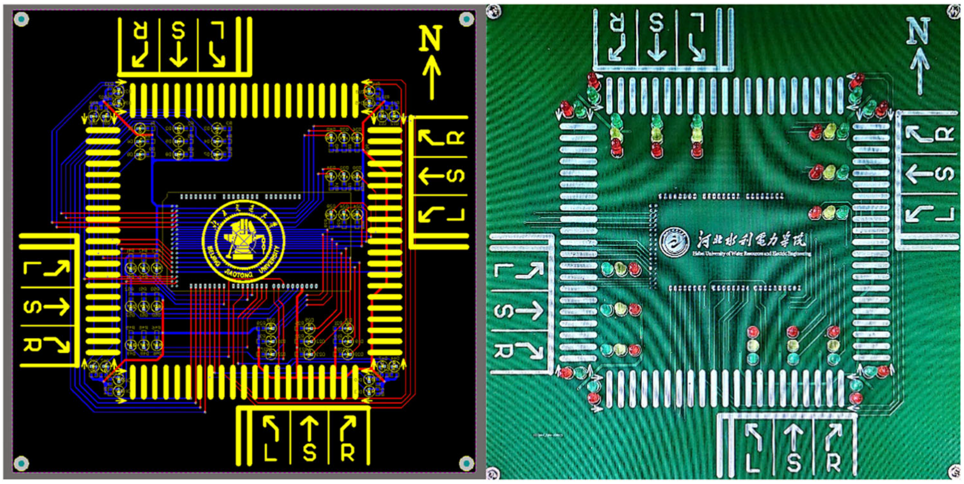

FIGURE 16 Circuit diagram and board diagram.

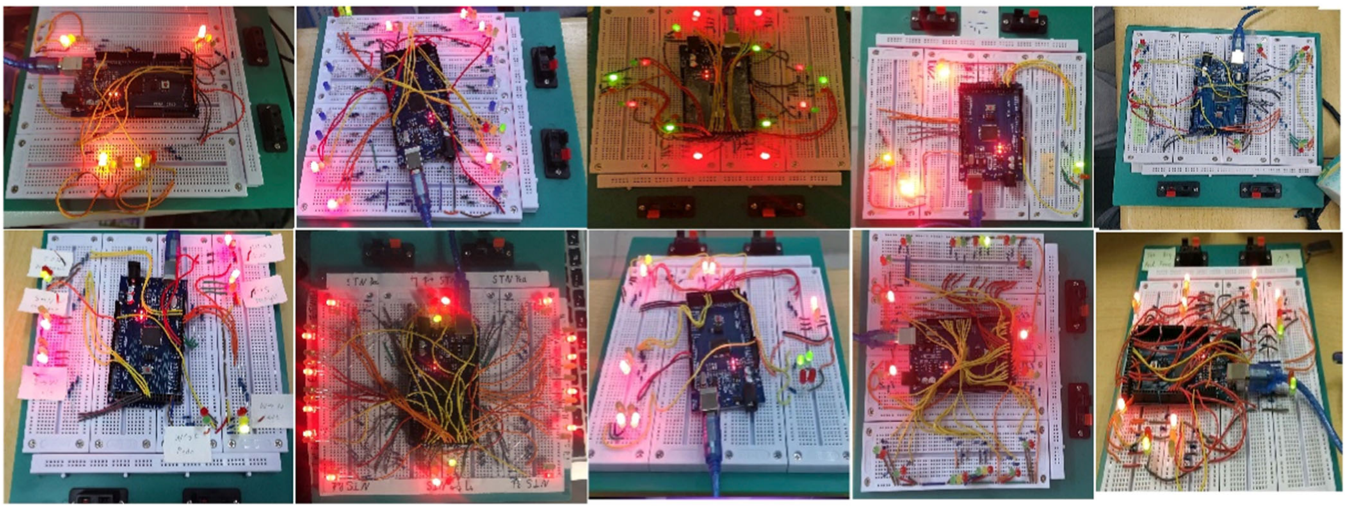

FIGURE 17 Primitive prototypes manufactured by 10 student groups.

of the teams submitted the four-leg intersection controller. Moreover, the creativity of the undergraduates was stimulated. Due to the open hardware and the portability of OOP, some of them had incorporated new features, for example, green wave scheme and customized printed circuit board (PCB) controller with cloud services (see Appendices for detailed assignment reports).

5 | RESULTS AND DISCUSSION

To evaluate teaching and learning in this practical activity, a questionnaire was designed and distributed to student participants. According to Edström, the questionnaire evaluates education from three aspects: teaching, learning, and student satisfaction [12]. A comprehensive anonymous evaluation was finalized at the end of the semester. The evaluation surveys the course and the instructor separately according to the program partner regulations [11]. Since student satisfaction is subjective and influenced by other factors, the factor analysis is especially critical for the survey. The survey largely follows the Student Evaluation of Educational Quality (SEEQ) on a one-to-five scale structure and some elements of the SEEQ form, especially learning, group interaction, and breadth of coverage, out of nine aspects [23]. In the proposed case study, teaching is prone to be student-centered. Hence, the learning component was the focus of the evaluation of the education program. The questionnaire assessed the learning process and outcome in relation to the learning content, learning

FIGURE 18 Finalized prototype submissions by students.

method, and the practical activity's effect on learning. After distribution, 57 valid responses were received out of 60 questionnaires. The content and results from the core questions are shown in Table 5. More contents and results linked to Questions 9 and 10 are shown in Table 6 and Figure 19.

Based on the results for Questions 2, 7, and 8, they preferred practical activities to help them understand the knowledge they were learning. Moreover, over 90% of student participants commented positively on group learning. According to the results for Questions 3, 4, and 5, the undergraduates thought that community learning played an important role in the case study. Questions 9 and 10 evaluate the understanding and acceptance after finalizing the case study, and they offer multiple options covering four domains of engineering knowledge to assess the tasks and an open supplementary answer. According to Question 9, the vast majority of student participants believed that their diverse skills were important. Four overlapping subcomponents, namely, knowledge of traffic engineering, programming, electronic circuits, and manufacturing, were highly regarded by the participants. According to question 10, at least half of the participants (29 out of 57) had accepted the merging teaching methodology on each task. Although a few disagreed, most undergraduates thought this case study was better than conventional lectures. Most undergraduates acknowledge electronic circuits and programming are essential tasks, but their acceptance of these is not the highest. It suggests that object-orientated programming may still be a skill gap for some undergraduates. The manufacturing component is not as popular as other tasks. Nevertheless, it is an indispensable and time-consuming component. The design of instruction should be enhanced in the future. A few undergraduates also regarded group cooperation and analysis abilities as necessary and important skills for the open answer.

The case study selects a well-structured problem for third-year undergraduates. With the careful design of instruction, the undergraduates were clustered into small groups to ensure full participation. The case study focuses on a well-defined problem to deliver a solution for a real traffic problem. The case study is a trans-domain one. It is organized into a series of correlated tasks, and each task is self-contained with a clear target and scope. The participant undergraduate needs to be trans-domain. Each task needs a specific profession with trans-domain knowledge. Therefore, the assessment components are according to the case study's intrinsic structure. In this case, the formative assessment should be applied to assess the depth of the knowledge acquired by the student and the contributions of each group member in the community learning case [34].

TABLE 5 Contents of core questions and responses.

Question	Contents\Responses	Strongly agree (%)	Agree (%)	Neutral	Disagree	Strongly disagree
1	Overall, I benefit from the case study	84	9	7%	0	0
2	Teamwork practice is more motivating than the conventional teaching method of lectures	95	4	2%	0	0
3	Teamwork is positive for learning	95	4	1%	0	0
4	Intra-group coordination and communication in the group are important	93	7	0	0	0
5	Intergroup communication helps a lot	91	9	0	0	0
6	The education program improves trans-domain skills	89	11	0	0	0
7	Similar education practices are preferable in the future	89	7	7%	0	0
8	The education program delivers a more profound understanding of traffic engineering	89	9	2%	0	0

Note: The total percentage may not equal 100% due to rounding.

TABLE 6 Content of Questions 9 and 10.

Question	Contents
9	Basic skills in terms of traffic signal phase design, electronic circuit manufacturing, and OOP coding are important in engineering practice.
10	The basic skills have been improved in practice.

Abbreviation: OOP, object-oriented programming.

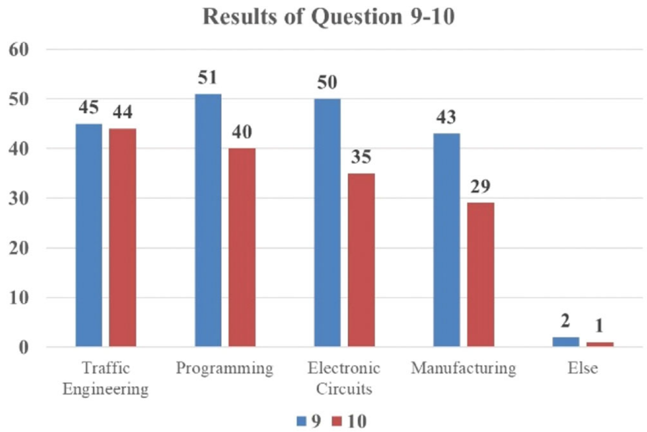

FIGURE 19 Results of teaching content perception surveyed by Question 9 and study outcomes surveyed by question 10*. * The numbers over the column are the data of affirmative questionnaire answers.

From the study's results, it can be concluded that the case study benefited almost all the students. The case study provides not only technological insight into the field of intersection signalization but also an overview of engineering practice. The evaluation results also provided evidence that worked example based on the open source hardware and OOP code can deliver both an excellent process and a successful outcome. Therefore, promoting this new teaching pedagogy to higher education institutes and more courses is worthwhile.

The contents, course delivery, and teaching activity objects are different from the conventional ones. Although statistical analysis, including mean scores, standard deviation, χ^2, t value, and p value, had been conducted in different research designs [4]. A direct comparison of exam marks or assessments is invalid due to insufficient comparability, and the results can even be misleading. Thus, the authors have pledged to open all materials, including driver code and circuit design. Therefore, the integrated design case studies can be compared in varied conditions to conduct a cross-study further. Besides preparing texts, demonstration kits, and codes, teaching in the lecture room somewhat belongs to art craftsmanship [27]. While some principles and methodologies can inform effective teaching practices, there is also a teaching art that involves creativity, intuition, and adaptability. This study applies a longitudinal comparison for case study evaluation. The finalized prototypes demonstrate conceptual understanding, schema invoking, and heuristic research. The finalized prototypes hold self-evidence of students' accomplishments and the efficacy of the proposed methodology. The case study presents two distinct group assignments in the attached appendices to demonstrate the following merits examples.

6 | CONCLUSION REMARKS

This article presents an emerging approach to course development that integrates design experience and inter-engineering domain learning. Based on the signalized intersection issue context, the article analyzed the intrinsic nature of the issue. Among the instructional models for well-structured problems, the proposed case study selects the worked example for this matured traffic engineering problem. The case study materializes the abstract concept of a worked example. The trans-domain teaching is applied to extend the issue's breadth. An accomplished set of phase design, circuit layout, and driver program constructs a representation as a worked example at the initial stage. The study arranges the schedule and tasks in the practical activity design, as well as the verification of the design to establish the schema for signal design at intersections. Since the students have acquired skills and knowledge, the instructors gradually fade from the learning process. The contents of the case study can be a detailed cookbook for other instructors.

The various prototypes independently finalized by autonomous teams are self-evidence. The acceptance of the schema demonstrates extracting underlying principles, digesting contents, and field implementation. The details of prototypes by undergraduates demonstrate insight into a specialized area of traffic engineering knowledge. The controller prototype is the simulation of the signal phase design, and the procedure is the simulation of the engineering development project. The case study requires the integration of various engineering branches. It begins with traffic engineering practice, followed by abstraction of the intersection, and finishes with the demonstration of presentable controllers. Dealing with a real-world engineering application in a company intrigued and motivated students to gain insights into various engineering domains. The attached two case studies in the appendix demonstrate technological endeavors. One case study finalizes a Greenwave corridor scheme case study to optimize phase design. The other improves the improvised breadnboard hardware, using PCB signal circuit instead. These indicate that heuristic search is activated as the students broaden the technological horizon of engineering study. The integrated engineering study surfaced in self-contained design assignments that applied knowledge from students' previous and current experiences. Based on the study's objective presented prototypes and survey results, the integrated design session improves learning experiences in each dimension. The caveats of the worked example learning have been addressed categorically by careful instructional design and some tips gained in the teaching practice.

The case study content presented the theory's essence and usefulness and a deeper understanding of the interaction of technological and managerial factors in transportation engineering. The design session simulated the development of a potential team project that required highly diversified skills and cultivated the division of labor and a sense of team cooperation. The design session also enhanced students' social skills not only through teacher instruction but also through peer instruction. To ensure the quality education, the curriculum needs to be designed accordingly. The first-year and second-year courses should deliver a solid foundation in Mathematics, Physics, and Computer Science. On the other hand, the engineering faculty should enable undergraduates to select courses in different domains to gain a holistic view of the traffic system. The varied professional courses with project-based problems can have synergistic effects. Last, the open hardware platform can be transferred to different classes at low impedance to fill the insufficiency in the cross-comparison.

AUTHOR CONTRIBUTIONS

All authors: Study conception and design. **Sicong Zhu** and **Wenjie Peng**: Data collection. **Qing Lan** and **Hangbin Wu**: Analysis and interpretation of results. **Qing Lan**, **Yufei Yuan**, and **Sicong Zhu**: Draft manuscript preparation. **Hangbin Wu**, **Qing Lan**, and **Lei Yu**: Study supervision. All authors reviewed the results and approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX A: STUDENT GROUP REPORT: GREEN WAVE SCHEME CASE STUDY*

* An abstraction of a revised student assignment

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Design principle of coordinated traffic signal control

A coordinated traffic signal system of two T-intersections is designed in the project. The intersection signal phase design consists of three phases, shown in Figure A1, where the four pedestrian movements are denoted with the initial P. The offset between consecutive intersections is optimized as 16 s according to a real-world road section. The signal timing settings of one T-intersection are shown in Figure A2.

Design of the hardware module

The module design adopted Arduino MEGA2560 board that has the advantage of multiple pins and convenient communication protocols of SPIs and I2C for the hardware side, and the board is controlled by Arduino IDE on the computer. The final design of the circuit board of one T-intersection is shown in Figure A3.

To achieve the synchronized timing between two circuit boards, an external clock is utilized and connected

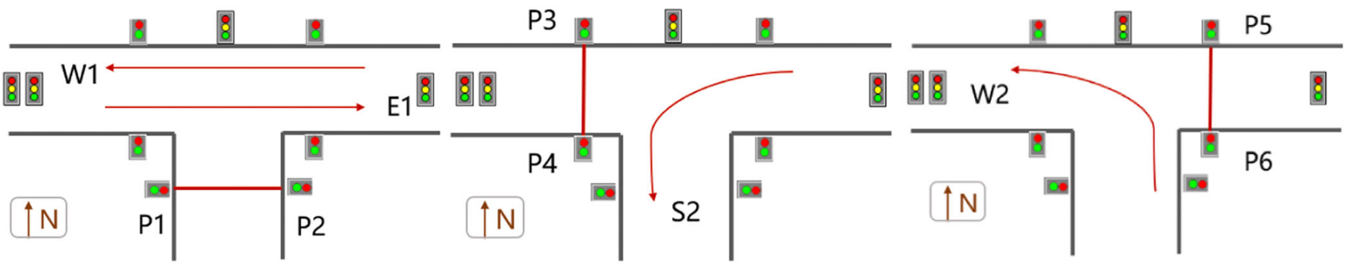

FIGURE A1 Three phases of one T-intersection.

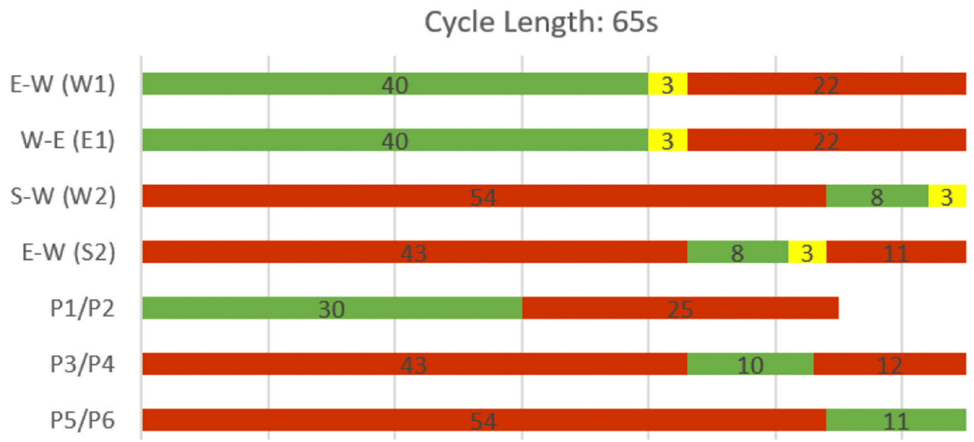

FIGURE A2 Timing setting of one t-intersection.

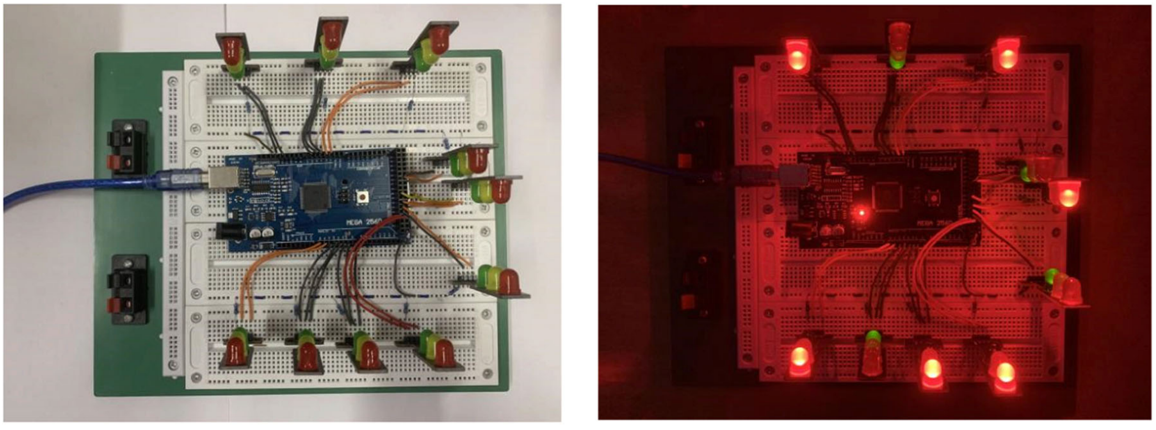

FIGURE A3 Bird-eye view of the T intersection design.

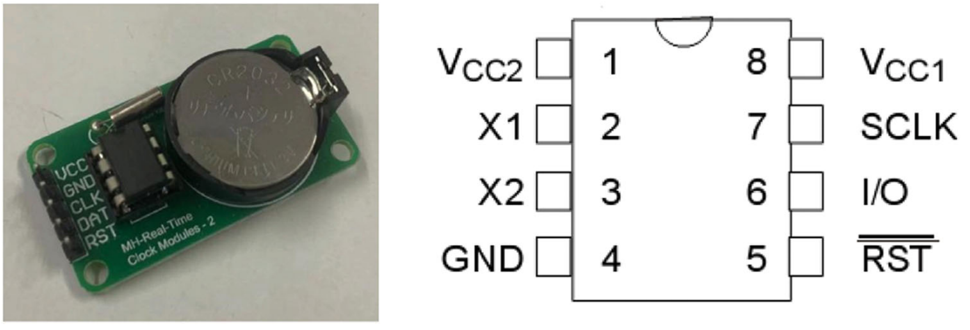

FIGURE A4 The external clock module and schematic diagram of pin-outs.

FIGURE A5 ESP-01S Wi-Fi module.

TABLE A1 Functions of Wi-Fi module PINs.

PIN	Function
3.3	3.3 V power supply(avoid 5 V power supply)
RX	UART_RXD, asynchronous serial port receiver
RST	external reset pin, active low, default high
IO_0	GPIO 0 pin 1. Suspended: Flash download mode and working mode 2. Drop-down: Serial port download mode
EN	enable the port, high level working, low level not working
IO_2	GPIO2 pin, no pull down when power-on, default high level
U_TXD	UART_TXD, asynchronous serial port sender
GND	Ground pin

to the module to guarantee the same internal clock time with the same accuracy between the two boards. The external clock module with DS1302 chip is selected, with the internal crystal oscillator being 32.768 KHz. The external clock is equipped with a CR2032 button battery that serves as a power supply to provide continuous timing without the need to charge.

The external clock module is connected to MCU under the instruction of DS1302 pin schematic diagram shown in Figure A4.

The communication between the two intersection signaling systems is implemented based on Wi-Fi technology. In the project, an ESP-01S Wi-Fi module equipped with ESP-8266 chip produced by *ESpressif* company is selected. The chip can work in three modes: AP mode, station mode, and hybrid mode, controlled by common AT instructions. In the design, the two ESP8266 modules are regarded as AP mode, which acts as the server, and station mode is viewed as the client to achieve mutual communication shown in Figure A5, Table A1.

At this stage, the circuit board of the coordinated T-intersection signal system has been manufactured, with the final design of the hardware module shown in Figure A6.

Based on C + + language OOP programming, the driver program of the green wave scheme between two T-intersections is established. The flow chart represents the design architecture of the program in Figure A7.

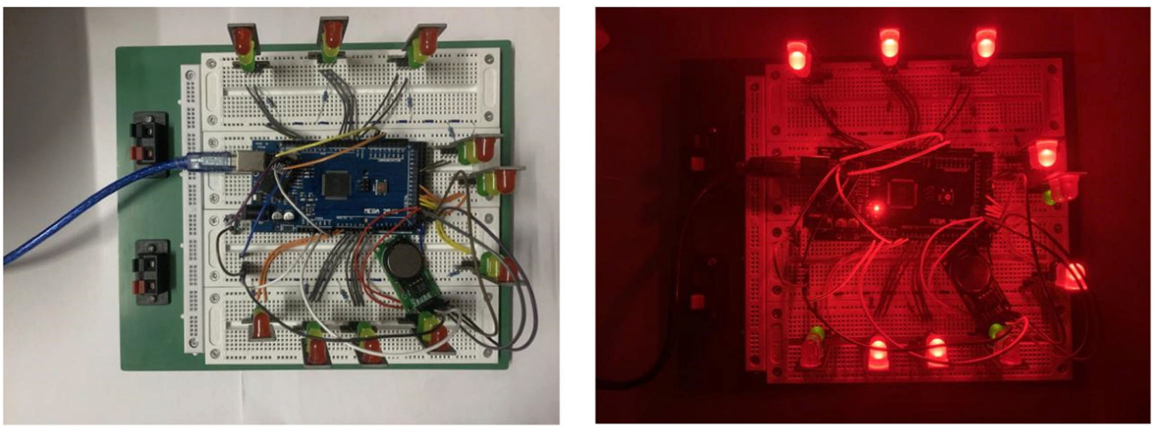

FIGURE A6 Bird-eye view of the Final T junction design.

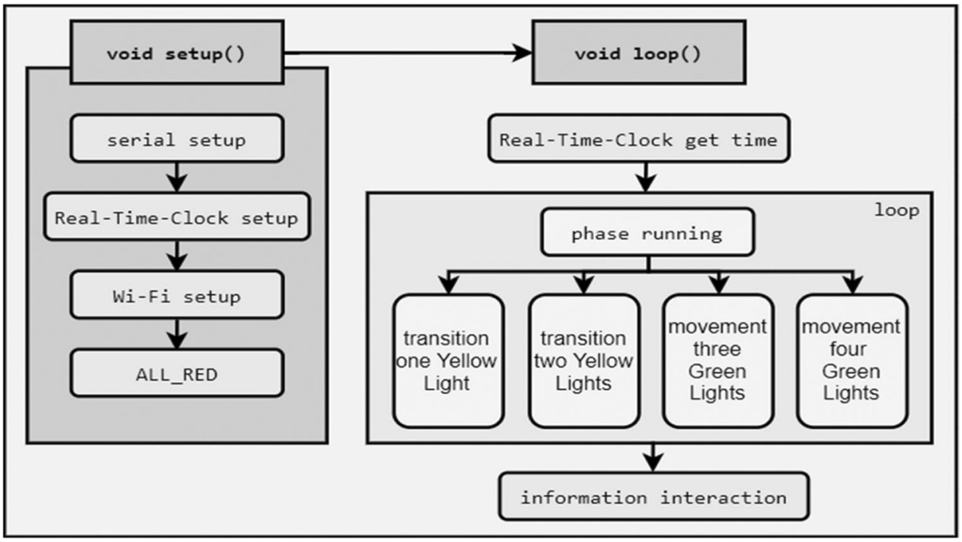

FIGURE A7 The architecture driver code of the green wave scheme.

APPENDIX B: STUDENT GROUP REPORT: PRINTED CIRCUIT BOARD (PCB) DESIGN AND REMOTE SIGNAL PHASE CONTROL*

* An abstraction of a revised student assignment

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Introduction

Based on the instructions provided by the lecturer, the student group engaged in creative thinking. To enable management personnel to achieve macro control of signal controllers, a signal management system should be capable of remote monitoring and remote control. Remote monitoring refers to the function that allows management personnel to browse specific information of the signal system in real-time, while remote control means that personnel should be able to modify the signal phase sequence and timing duration of the signal system remotely. The group chose Python as the development language to achieve these objectives and facilitate management. It utilized the Flask module to simulate POST and GET requests, creating a backend program. Furthermore, to make it convenient for management personnel to administer the system, the group developed a frontend using Vue3. Through this frontend program, authorized personnel can achieve the objectives of remote modification and monitoring.

Controller PCB design

At the project's initiation, the lecturer instructed us to use a breadboard for basic circuit design. To optimize the layout of the traffic signal intersection and reduce the number of circuits, the group decided to avoid failures at wire junctions and short circuits in favor of a circuit design on a PCB. A PCB primarily comprises an insulating substrate and conductive patterns formed from copper foil. These conductive patterns are created by printing a layer of copper foil on the insulating substrate and then etching away the excess to form the desired circuit layout. This method conceals the circuit wiring within the layers of the PCB, resulting in a more reliable circuit and straightforward layout, compared with hand-made wiring and breadboard.

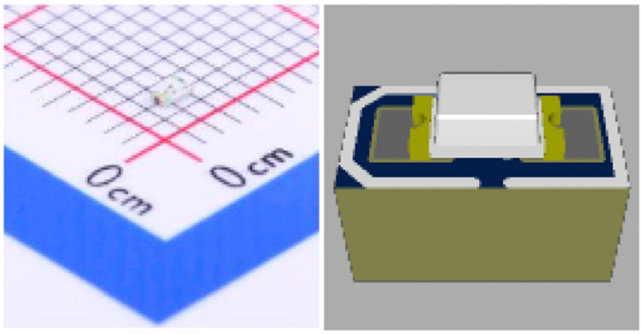


FIGURE B1 Light-emitting diode (LED) part selection and layout.

The group split the task to finalize the design: part selection and circuit layout. Considering that traffic lights typically consist of three colors: red, yellow, and green, the team chose 0603-sized (6 mm × 3 mm) surface-mount device LEDs to simulate the traffic lights, based on the size of the PCB and the scale of the simulated intersection controller. The type of LEDs is shown in Figure B1.

Furthermore, to connect our PCB with the Arduino controller, the group chose a pin header design to achieve a pin-to-pin connection with the Arduino controller. The style of the pin headers used is as shown in Figure B2.

After designing the pin connection method and selecting the LED part, the group began designing PCB. Considering the unidirectional conductivity of LEDs, it is essential to ensure that the current flows from the anode to the cathode of the diode. To control each LED, the group allocated an independent anode pin for each LED while connecting all cathodes collectively to the GND pin on the Arduino board for grounding. In Figure B3, the image shows an example of an LED circuit, indicating the direction of the current flow.

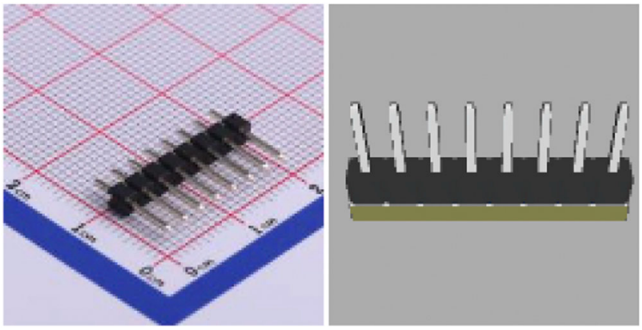


FIGURE B2 Pin header part selection and layout.

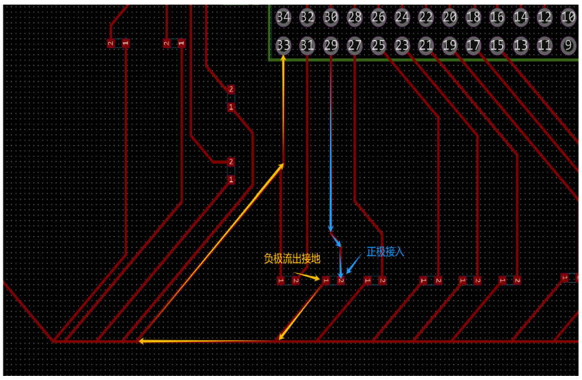


FIGURE B3 Single light-emitting diode (LED) circuit design layout details. * Anode and cathode connection

Finally, based on the considered design, the group designed the PCB as shown in Figure B4.

Backend program development

As mentioned in the introduction, the backend program should facilitate the querying and modification of the signal system.

Query module

To facilitate data storage, the group placed a file named "data" in the same directory as the Python program. This file contains information about the phase sequence and duration. When management personnel perform a query, the program opens the "data" file in read-only mode, reads the data, and then returns it in JSON format. The code is shown in Figure B5.

Update module

Before developing the update module, the group needed to clearly define the content that can be edited, the standard format for editing, and the scope of data editing. First, the road controlled by a signal system is an intersection with exactly four phases. Considering emergency situations, the group added a fifth phase where all traffic signals turn red. This phase can be activated during a severe traffic accident at the intersection to block all traffic flow, thereby reducing traffic casualties. Thus, the group has a total of five phases.

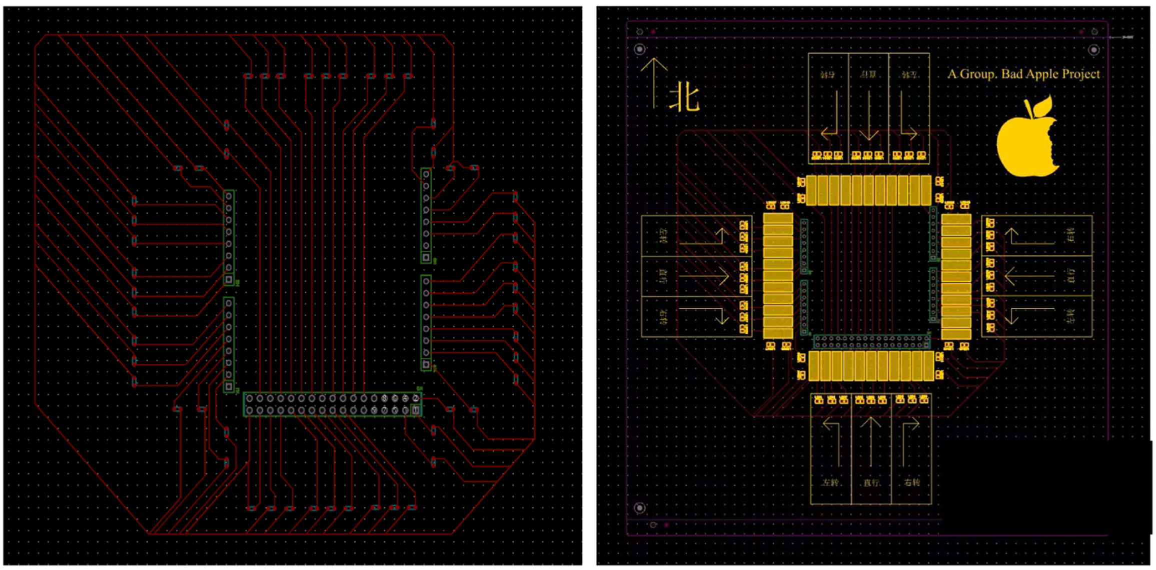


FIGURE B4 Overall printed circuit board (PCB) circuit layout.

```python
# 获取data文件的内容
def read_data():
    with open("data", "r") as f:
        lines = f.readlines()
        data = OrderedDict()
        for line in lines:
            phase, time = line.strip().split(":")
            data[phase] = int(time)
        return data
@app.route("/get_data", methods=["GET"])
@require_api_key
def get_data():
    data = read_data()
    return Response(json.dumps(data), mimetype='application/json')
```

FIGURE B5 The Json script of query module.

```python
# 将数据写入data文件
def write_data(data):
    with open("data", "w") as f:
        f.truncate(0)
        for phase, time in data.items():
            f.write(f"{phase}:{time}\n")

@app.route("/update_data", methods=["POST"])
@require_api_key
def update_data():
    expected_keys = {"phase1", "phase2", "phase3", "phase4", "phase5"}
    received_keys = set(request.form.keys())

    if received_keys != expected_keys:
        return jsonify({"error": "Invalid keys provided. Please provide all expected keys without duplication."}), 400

    new_data = {}
    for key, value in request.form.items():
        value = int(value)
        if value <= 3:
            return jsonify({"error": f"Value for {key} is too small. Must be greater than 3."}), 400
        new_data[key] = value

    if new_data:
        write_data(new_data)
        return jsonify({"message": "Data updated successfully!"})
    else:
        return jsonify({"error": "Failed to update data."}), 500
```

FIGURE B6 The Json script of data update module.

Consequently, any POST request with keys outside these five phases will be considered erroneous and result in an error. Second, since the yellow light duration is set to 3 s for our intersection under normal operation, any setting of a road passage time shorter than 3 s will be treated as an incorrect request and will also return an error message. When all requests are correct, the group opens the "data" file in read-write mode to make the changes. Based on these requirements, the group wrote the code as follows (Figure B6).

FIGURE B7 (a) Frontend phase information update interface. *Warning message of phase period length (b) Frontend phase information update interface. *Warning message of phase number input.

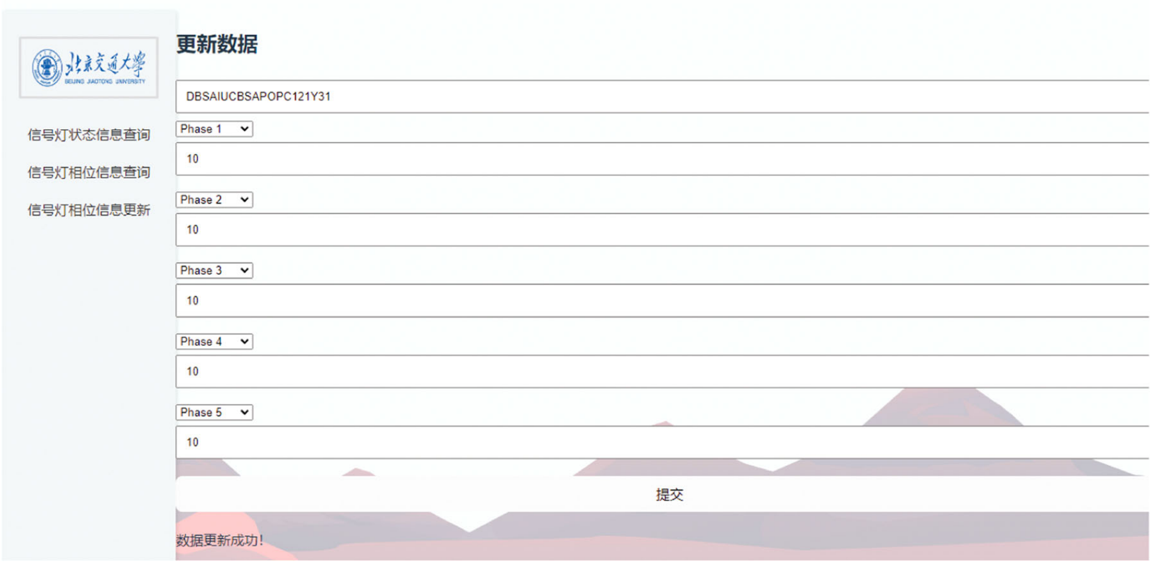


FIGURE B8 Frontend phase configurartion. * Message of successful signal phase configuration.

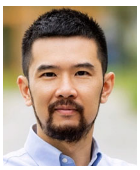
Frontend environment design

There is a traffic signal phase information update interface. First, the user needs to enter the corresponding API key. Next, the user should select the specific phase and the duration of that phase. If the user selects duplicate phase information or if the entered phase duration is less than 3 s, the system will display an error message and prevent information update, as shown in Figure B7.

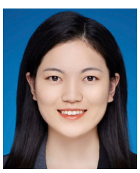
When the user inputs the correct information, it will be successfully updated and stored in the file on the server. as shown in Figure B8.

AUTHOR BIOGRAPHIES

Sicong Zhu is an associate professor at the College of Transportation & Traffic at Beijing Jiaotong University, where he has been a faculty member since 2015. Sicong completed his PhD at The University of Queensland and his undergraduate studies at Tongji University. His research interests lie in sustainable traffic studies, ranging from particulate matter monitoring to active mode traffic. He has collaborated actively with researchers in several other engineering domains, particularly ITS.



Yufei Yuan received an MSc degree in transport and planning and a PhD degree from the Delft University of Technology (TU Delft), Delft, The Netherlands, in 2008 and 2013, respectively. He is currently a senior researcher and co-director of the active-mode lab with the Department of Transport and Planning, TU Delft. His research interest has been focusing on traffic flow theory and simulation, data mining and processing, traffic state estimation and prediction, traffic management and analysis under evacuations and large-scale events, and intelligent transportation systems in general for "fast" vehicular traffic. In recent years, his working area has been extending to "slow/active modes," including pedestrian, bicyclist, and micro-mobility flows, covering data collection, behavioral interpretation, modeling underpinning, simulation implementation, and data-driven applications.



Wenjie Peng received her master's degree in 2021 from Beijing Jiaotong University. She was the coordinator of the tutoring team during tutorial delivery and was in charge of provisional breadboard manufacturing and PCB design before class commencement.

Hangbin Wu received his BE degree in surveying and mapping engineering and a PhD degree in geodetics from Tongji University, Shanghai, China, in 2005 and 2010, respectively. He is currently an Associate Professor with the College of Surveying and Geo-Informatics, Tongji University. He has contributed more than 50 publications on the topic of his research interests, which include the collection and processing of point clouds, high-definition maps for autonomous driving, and data mining from BIG navigation data. The main courses he is involved in are computer-aided graphics and data communication technologies.

Lei Yu is a professor at Shandong Jiaotong University. His research interests include vehicle fuel consumption/emission modeling, intelligent transportation systems, connected vehicle technologies, and urban traffic control and management. He has conducted over 120 funded projects and published over 200 journal papers. Yu is a professional engineer registered in the State of Texas, USA. He received his PhD degree in Transportation Systems Engineering from Queen's University (Canada), MS Degree in Production and Systems Engineering from Nagoya Institute of Technology (Japan), and Bachelor of Engineering Degree in Railway Transportation Management Engineering from Beijing Jiaotong University (China). He is a member of Institute of the Transportation Engineers (ITE), American Society of Civil Engineers (ASCE), and Transportation Research Board (TRB).

Prof. Qing Lan is the director of Hebei Higher Institute of Transportation Infrastructure Research and Development Center for Digital and Intelligent Technology Application, Hebei University of Water Resources and Electric Engineering. He has been a seasoned engineer since graduating from Hebei University of Technology. His research is mainly based on his professional practices. The scientific research won the first prize for scientific and technological progress award from the Department of transportation, Hebei province. These research topics have summarized and refined local standards, invention patents, and professional papers. The main research is on road safety and the environment, mainly using interdisciplinary biotechnology to analyze and research current road signs.