Development of Knowledge Tables and Learning Outcomes for an Introductory Course in Transportation Engineering

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Many decisions about the content of an introductory transportation engineering course are complicated by a wide range of topics and skills to be presented in a limited amount of time. The information presented in this paper was compiled by a working group of educators who represented universities of varying sizes and geographic areas. This working group was charged with developing core concepts and associated knowledge tables for the introductory transportation course for the following core concept areas: traffic operations, transportation planning, geometric design, transportation finance, transportation economics, traffic safety, and transit and nonmotorized transport. Instructors can weave the knowledge tables together by explaining the ways of being of a transportation professional and the course learning outcomes. A key focus of the working group's efforts was to provide more guidance to instructors on core content versus optional content. The intent of the working group was not to dictate what exactly should be taught in a course. The group therefore created more content than could fit into a typical semester-long course so that instructors would have flexibility. Some content should be viewed as more critical to the transportation profession than other material, and the working group will prioritize it accordingly. The objective of this paper is to demonstrate the work that has been completed and to get feedback from industry partners and other academic professionals about the curriculum. The efforts of the pilot studies over the next year will help determine the amount of time needed to cover the information in the knowledge tables.

Students, faculty, and potential employers are all stakeholders in the determination of content in a college course. For many courses, content decisions are complicated by a wide range of knowledge and skills and a limited amount of time. The introductory transportation engineering course is one of these courses. With typically only one required course in the transportation field in most civil engineering programs, faculty often have about 40 contact hours with students to discuss how complex transportation systems are designed, built, maintained, and operated for different types of transportation modes (*1*). The breadth of the transportation field often causes this introductory course to be filled with an overabundance of topics that can be viewed by the students as seemingly shallow and unrelated. One result of focusing on breadth can be inadequate time to investigate the more important topics in depth, which can lead to a less challenging experience for students in the course. Difficulties with course content in the introductory transportation course area often are cited as barriers to the recruitment of students into the field (*2*).

These issues were the focus of the Transportation Education Conference held in Portland, Oregon, in June 2009. More than 60 participants learned about, and discussed issues related to, transportation engineering education, with a particular focus on the traditional introductory transportation course. A primary concern identified at this conference was the need for specific learning outcomes for the introductory course (*3*). A working group of transportation educators was assembled at this conference and has been working to address this concern over the last year. Through regular conference calls, conference papers, presentations, and a 1-day workshop at TRB's annual meeting in January 2010, this working group has made significant progress on the development of knowledge tables in the key areas of transportation and on learning objectives for the introductory course. As part of its work, the group has interacted with both academic and nonacademic stakeholders to solicit feedback. The working group has grown from an original six educators to nearly 20. As shown in Figure 1, members of the working group represent 13 universities of varying sizes and geographic areas. Table 1 provides supplemental information about the programs of the working group members. The schools' enrollments range from 2,000 to more than 40,000 students and anywhere from 150 to almost 600 registered civil engineering undergraduates. Most of the schools require one course in transportation engineering, but the length of the course varies.

This paper outlines the working group's efforts and presents the results. The paper begins with a discussion of learning outcomes—what students should know and be able to do after completing the introductory transportation engineering course—followed by an exploration of the ways of being that the course should foster. The next section explains one of the knowledge tables that the group has developed. Knowledge tables articulate the core concepts for such a course; the full set of tables is included at the end of the paper. Finally, the paper outlines in more detail the process to date and the next steps.

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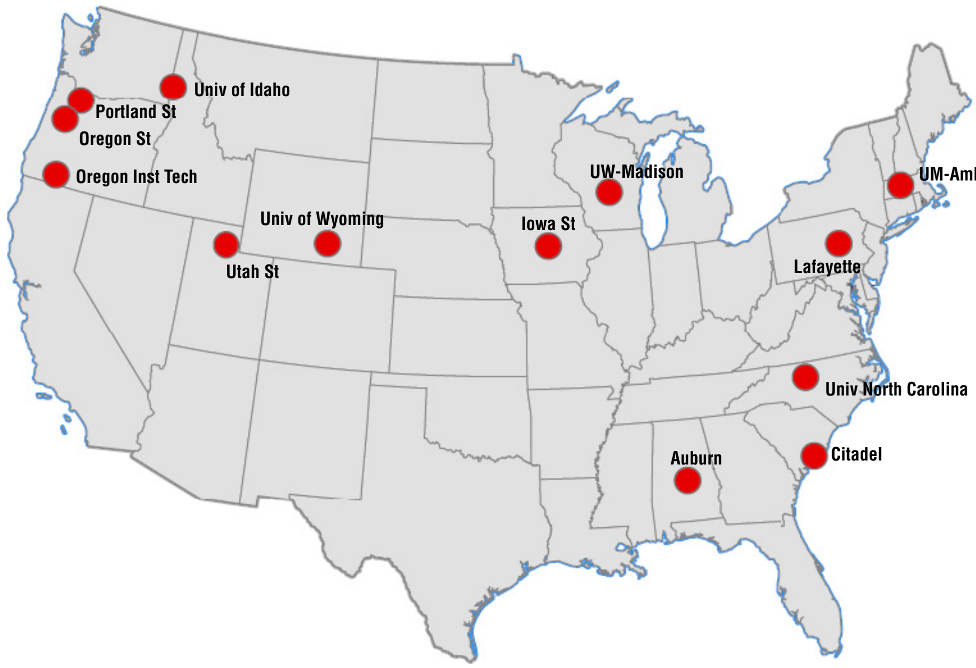

FIGURE 1 Location of working group members.

LEARNING OUTCOMES

When appropriately designed, learning outcomes specify the level of mastery that students will achieve at the culmination of a particular learning experience. This research effort was concerned with course-level learning outcomes, constructed for the introduction to transportation course.

Learning Outcome Classification

It is well accepted that a wide variety of learning outcomes occur, regardless of the manner in which they are defined. Wiggins and McTighe have suggested that educators can improve the alignment of classroom instruction with assessment and evaluation techniques through the careful consideration of different learning outcomes (*4*).

TABLE 1 Working Group Member Profile

Member	School	School Size; Program Size	Introductory Transportation Course
Rod Turochy	Auburn University	24,602; 615	Required 3-credit semester junior-level course
Michael Kyte, Steve Beyerlein, Michael Dixon, Ahmed Abdel-Rahim	University of Idaho	11,957; 176	Required 3-credit semester junior-level course
Shashi Nambisan	Iowa State University	28,000; 600	Required 3-credit semester junior-level course
Kristen Sanford Bernhardt	Lafayette College	2,400; 120	Required semester course with lab component (sophomore or junior)
Roger Lindgren	Oregon Institute of Technology	3,484; 115	Required 3-credit semester junior-level course
Ida Van Schalkwyk, David Hurwitz	Oregon State University	19,352; 489	Required 4-credit course, offered in a quarter system, highway engineering focus
Ashley Haire, Kent Lall	Portland State University	30,000; 150	Required 2- to 4-credit courses, offered in a quarter system (junior and senior)
William Davis	Citadel	2,000; NA	Required 4-credit semester junior-level course
Michael Knodler	University of Massachusetts, Amherst	27,016; 350	Required 3-credit semester junior-level course
Laura Sandt	University of North Carolina	28,000; NA	Required semester transportation-planning class
Andrea Bill	University of Wisconsin–Madison	42,099; 350	Required 3-credit semester course (junior or senior)
Rhonda Young	University of Wyoming	12,875; 250	Required 3-credit semester junior-level course
Kevin Heaslip	Utah State University	25,000; 380	Required 3-credit semester (sophomore or junior)

NOTE: School size is the approximate number of students on that campus. The program size is the approximate number of undergraduate students enrolled in the civil engineering (or equivalent) program. NA = not available.

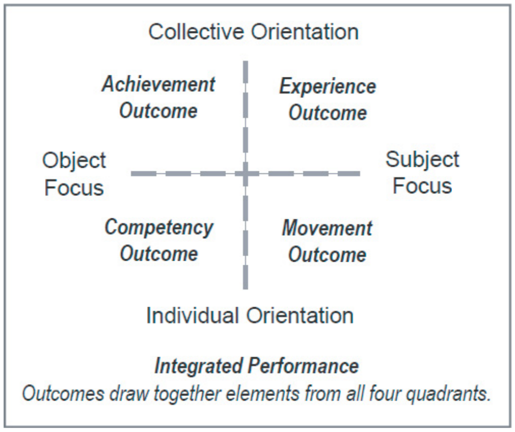

FIGURE 2 Types of learning outcomes mapped to axes of social learning (*6*).

Wenger proposed a mapping of learning outcomes across two dimensions (*5*). This model describes four quadrants defined by one axis that denotes who is learning (subject) and what is being learned (object) and a second axis that segments the learning as either collective or individual, as shown in Figure 2 (*6*). The four learning outcomes generated from this division are (*5, 6*)

- Competency outcomes, which describe the mastery of technical content;
- Movement outcomes, which track the improvement of technical skills over time;
- Experience outcomes, which can take place in a person or group and typically help in the clarification of goals; and
- Achievement outcomes, which describe significant advances or achievements in the technical body of knowledge germane to the field.

The fifth and final learning outcome draws from a combination of the previous four (*5, 6*): integrated performance outcomes describe the combination of outcomes from all four of the previous categories in an attempt to address a complex challenge.

Unique Transportation Learning Outcomes

Table 2 presents 13 individual learning outcomes that have been identified as critical to the introduction to transportation engineering class. No accomplishment outcomes are associated with this class, because such outcomes would not occur in the classroom but rather as a result of professional practice.

Course Creation

Table 2 provides a suite of learning outcomes that can be integrated into the introduction to transportation engineering course. In reality, every course will be different and reflect the interests of the instructor and the student population. The learning outcomes selected will depend on contextual factors unique to each program. The length of the course (semester versus quarter), the presence of a complementary laboratory section, whether the course is required or is an elective, the courses that will follow the introductory course, and the nature of the institution (teaching versus research) will influence the learning outcomes the instructor chooses for the course. The important role of the learning outcomes is to have students master as many outcomes as possible before graduation from their undergraduate program.

A significant consideration for an instructor, who designs a course on the basis of these learning outcomes, will be whether or not further courses in transportation engineering are offered in the program, and whether those courses are required or elective. An instructor in a program that does not offer additional courses in transportation will face some difficult choices in the prioritization of what is most essential. Although depth is not possible in all of the core competencies, movement outcomes may be a priority. Experience and performance are significant. The significance, however, will come from the breadth of the experience rather than from the depth of the experience. An instructor in a program that offers several transportation courses may design the introductory course to have depth in one or more areas, comforted by the knowledge that other outcomes will be realized in future courses.

A laboratory component of the course provides supplemental opportunities to add depth to the learning outcomes and engage students through hands-on and data-driven experiences.

WAYS OF BEING

Ways of being are sets of behaviors, actions, and language associated with a particular discipline, knowledge area, or culture. They reflect preferences, tacit assumptions, and conventions rather

TABLE 2 Learning Outcomes: Introduction to Transportation Engineering

1. Competency	2. Movement	3. Experience	4. Integrated Performance
1.1 Complete a geometric design for a section of a transportation facility 1.2 Complete level-of-service analysis for basic freeway segment 1.3 Complete signal timing design for fixed-time isolated intersection 1.4 Design and conduct a safety analysis 1.5 Forecast demand for a transportation system 1.6 Explain pavement design by referring to standard design and procedures	2.1 Able to apply the scientific method to transportation problems 2.2 Able to explain relationship between components of the transportation Venn diagram and appreciate how course content supports these relationships 2.3 Increasingly able to connect theory with field observations and to identify limitations in theory or models	3.1 Connect driving and pedestrian experiences with transportation terminology and common or classic transportation engineering problems (e.g., safety, congestion, energy, and the environment) 3.2 Heighten awareness of the global transportation system that connects producers and consumers	4.1 Integrate design, operations, and planning concepts to create a traffic-impact-analysis project 4.2 Integrate complete streets principles in planning, design, and operations of a transportation system

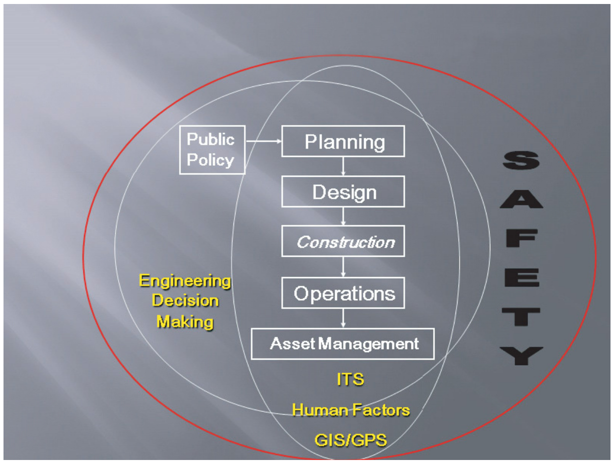

FIGURE 3 Transportation delivery process (ITS = intelligent transportation system, GIS = geographic information system, GPS = Global Positioning System).

than discipline-specific knowledge. Ways of being help faculty and students visualize long-term behaviors (formed over multiple years of training and practice) that support personal and professional success in the discipline. They should be meaningful within the context of a course in ways that are accessible and demonstrable by at least some students in the course.

Five ways of being for a transportation engineer permeate the Venn diagram, shown in Figure 3. Each way of being is defined in Table 3, along with supporting life-long skills that can be woven together with technical content in meaningful learning activities for the course. The lifelong skills associated with each way of being include a mixture of cognitive (C), social (S), and affective (A) skills.

KNOWLEDGE TABLES

Knowledge tables articulate the core concepts for a course. The working group began with the broad scope of the transportation discipline and, by using existing surveys of academics and practitioners, applied several different methodologies to organize the knowledge (*1*).

Knowledge can be organized in a variety of ways. A review of a variety of existing methods for organizing knowledge was conducted. It included Bloom's taxonomy and Wiggins and McTighe's facets of understanding, as well as the efforts of other groups to determine what students should be learning (*4, 7–11*).

The review of the literature led to the adoption of a knowledge table framework that includes five forms of knowledge (*12*):

- Concepts: learning based on definitions, diagrams, and models;
- Processes: learning based on methodologies (eg., information processing, design, teamwork, communication);
- Tools: learning that surrounds forms and templates, software, and lab equipment;
- Contexts: situations in which knowledge is applied; and
- Ways of being: attitudes and values that surround learning.

Ways of being should be defined for the course as a whole, as discussed earlier.

To help instructors as they develop the learning activities within a course, the group has made an effort to frame items within each form of knowledge as belonging to a level of Bloom's Taxonomy, to a facet of understanding, or to both. This hybrid framework conceptually yields a two-dimensional table for each topic (as identified through the previously mentioned surveys and prioritized by the group). The knowledge tables provide direction for instructors to use in designing a course. They are not meant to prescribe every aspect of a course but rather to provide a measure of guidance for instructors in the selection of core content. A knowledge table for a particular topic may encompass more than an individual instructor chooses to include in a course;

TABLE 3 Ways of Being

Way of Being	Definition	Lifelong Skills
Planner	Anticipating future conditions or needs, the engineer gathers appropriate data, uses appropriate tools, and engages constituents to envision and assess possible courses of action.	Cooperating (S) Exploring context (C) Preparing (A) Envisioning possibilities (C)
Decision maker	When faced with a need to choose among alternatives, the engineer demonstrates initiative, focus, and accountability in recommending a course of action.	Identifying key issues (C) Choosing among alternatives (C) Accepting responsibility (S) Checking perceptions (S) Being decisive (A)
Designer	When facing a design challenge, the engineer develops robust and well-documented designs based on engineering principles and tests the design against stakeholder needs.	Goal setting (S) Simplifying (C) Validating (C) Documenting (S) Seeking assessment (A)
Safety advocate	Acting from a deep understanding of interactions between the driver, the vehicle, and the roadway, the engineer is keenly aware of safety implications associated with design and policy decisions.	Analyzing risks (C) Thinking skeptically (A) Obeying laws (S) Challenging assumptions (C)
Public servant	Driven by personal and professional values, the engineer proactively engages in the political process and demonstrates integrity and responsibility in engineering practice.	Respecting (A) Being self-disciplined (A) Appreciating diversity (A) Identifying stakeholders (C) Influencing decisions (S)

conversely, an instructor may choose to go beyond the knowledge table for a particular topic.

The items in the knowledge tables can be used to design the learning activities in a course. In particular, the level at which they are classified (through Bloom's taxonomy and Wiggins and McTighe's levels of understanding) suggests what types of learning activities might be most appropriate.

Seven knowledge tables have been developed:

- Traffic operations,
- Transportation planning,
- Geometric design,
- Transportation finance,
- Transportation economics,
- Traffic safety, and
- Transit and nonmotorized transport.

Figure 4 shows the current version of the knowledge table for transportation operations; the other six tables are shown in Figures 5 through 10.

Concepts associated with traffic operations can be divided into those associated with uninterrupted flow and those associated with interrupted flow. They include definitions, such as capacity and delay, as well as models, such as Greenshields' model and gap acceptance models. These concepts are necessary for students to grasp before they can apply them in processes. Examples of processes include determination of the capacity of a segment and establishment of cycle lengths. Students are introduced to tools, such as queuing models and exhibits from the *Highway Capacity Manual,* which they can use to facilitate the processes. Finally, students learn how these concepts, processes, and tools apply in the larger context of planning or designing a facility. If an instructor chooses not to include all elements of the knowledge table, he or she will select the items from each category that relate to one another. If, for example, an instructor chose to address only uninterrupted flow, he or she would omit those concepts related to interrupted flow, as well as the processes related to signalized intersections, and the tools of queuing theory.

The group is continuing to refine and vet the knowledge tables with a diverse group of stakeholders, as described in the next section.

NEXT STEPS

For the efforts of the working group to be most useful to the transportation community, the results need to be fully vetted with the greater stakeholder community. Key future steps will be to hold another workshop, publish and present follow-up papers on the topic, pilot the knowledge tables and course learning outcomes in introductory transportation courses, and assess those pilot projects.

At the August 2010 Institute of Transportation Engineers (ITE) annual meeting in Vancouver, British Columbia, Canada, a 1-day workshop and a conversation circle session kicked off the outreach efforts. One of the primary objectives of this workshop was to begin the discussion with the larger professional community on the knowledge tables and learning outcomes. Participants in the workshop included working group members and outsiders recruited through ITE's Public Agency and Consultant's Council. Two days later, a conversation circle session at the ITE annual meeting was held to reach a broader audience. The conversation circle format consisted of short presentations followed by a moderated discussion with audience members.

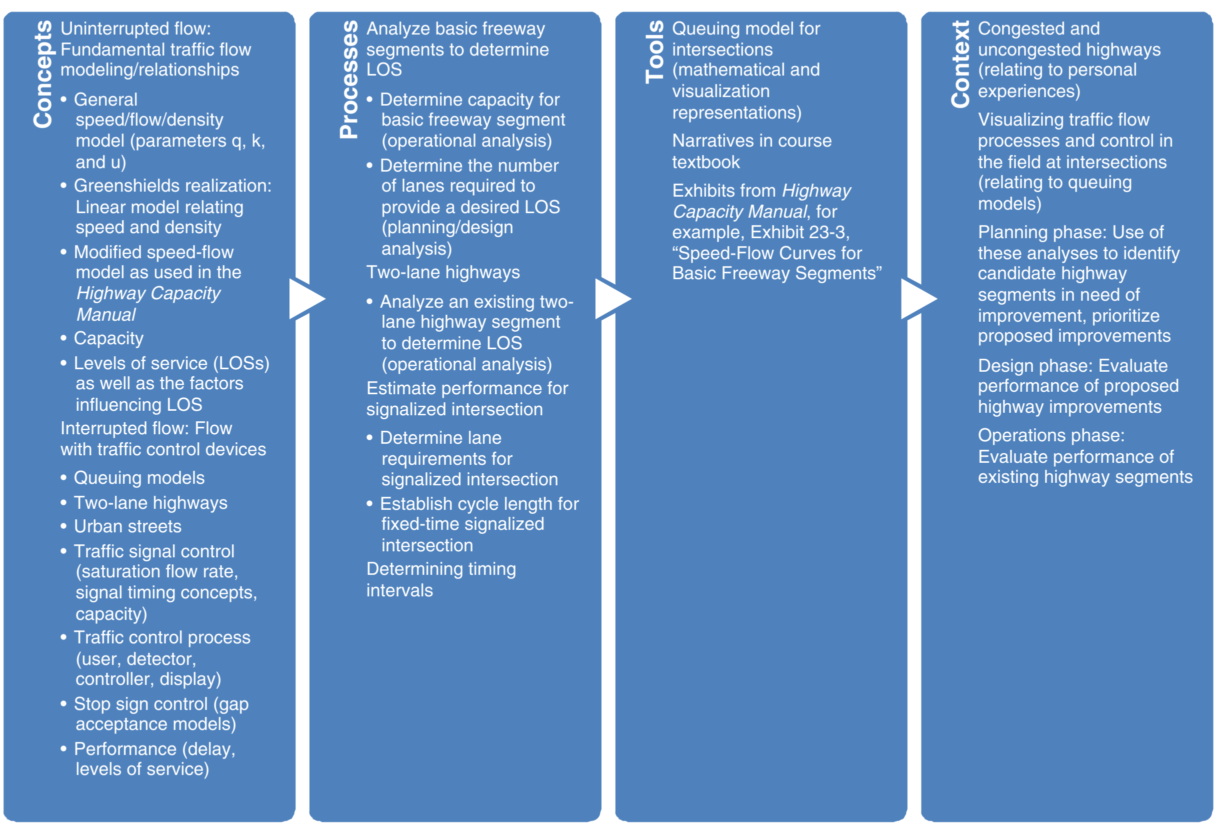

FIGURE 4 Traffic operations knowledge table.

Concepts

- Process to establish a vision, goals/priorities, assess opportunities and alternatives, present information, implement activities/investments, and evaluate
- Conceptual models of decision-making (rational, incremental, advocacy) and trade-offs
- Relationship between land development and transportation supply/demand
- Types of transportation/development impacts: natural/environmental, social/cultural (including health), economic impacts, and traffic flow/congestion
- Impact on different roadway users and methods to mitigate impacts for different modes
- Relationship between transportation planning and four-step model (see above concept)
- Relationship between transportation supply (personal and social costs of travel, and externalities) and demand (travel and induced demand)
- The importance of pricing transportation for externalities
- Impact of policy on supply and demand, with examples (e.g., parking policies, congestion pricing, road widening, and TDM)
- Characteristics of land development: land use, development intensity, and location/context
- Reciprocal relationship of land development and transportation planning
- Relationship with economics supply/demand (see above concept)
- Concept of origin-destination (reference to four-step model)
- Land use models and implications for transportation (e.g., school siting)

Processes

- Travel demand modeling (TDM) forecasting
- Perform trend analysis (if included at all, this should be limited)
- Develop sketch plan (promote this approach)
- Use four-step model
- Transportation/development impact assessments
- Estimate development impacts: When/where, approach taken, what impacts to evaluate, what methods to use
- Develop impact models: Air quality, noise, fuel, water, health, LOS (can reference other LOS topics elsewhere), etc.
- Economic analysis
- Perform cost-benefit analysis
- Perform cost-effectiveness analysis
- Perform economic analysis
- Apply methods to evaluate externalities: Assess market valuation (when goods are exchanged in the market) and/or contingent valuation (using methods like willingness to pay, etc.)

Tools

- Software/data
- Census data: Census Transportation Planning Package (CTPP)
- GIS (include if there is a lab section; otherwise remove)
- Textbooks
- Highway Capacity Manual
- Models
- ITE Trip Generation Models (note limitations/criticisms)
- Mode choice and trip distribution models (application/Excel-based models)
- Macro and micro simulation models
- Surveys/data collection
- Origin/destination surveys
- Revealed preference and stated preference surveys
- Traffic counts (cordon, intersection) for all modes (including ped/bike)

Context

- Attending public meetings/input sessions
- Geographic levels/scales of plans and processes: Parcel/site, corridor/small area, region/city, statewide
- Economics case studies
- London congestion charging scheme
- High-occupancy toll (HOT) lanes
- Examples of induced demand: "Cannot build out of congestion"
- FTA criteria for new starts

FIGURE 5 Transportation planning knowledge table.

Concepts

- Mapping and survey practices to create base mapping for use in geometric design.
- Mapping precision and error
- Plan reading and highway stationing
- Photogrammetry
- Digital terrain models
- Route selection
- Selection of design parameters
- Design speed
- Stopping sight distance
- Max grade
- Cross-sectional elements: Lane width, shoulder width, median width, pedestrian and bicycle facilities
- Pavement cross slope (including max. Superelevation rate)
- Roadside parameters: Clear zone width, foreslope rates
- Functional classification
- Human factors: Design driver
- Roadway alignment
- Horizontal curve types: Simple, transitional (spiral), compound, reverse
- Vertical curve types: Sag, crest
- Simple horizontal curve components: Radius, length, tangent, chord, delta
- Vertical curve components: Length, back tangent grade, forward tangent grade, algebraic difference in grades, low-/high-point elevations
- Superelevationof horizontal curves: Superelevation rate, tangent run out, superelevation runoff
- Broader geometric design decisions are based on safety, capacity, cost, and other environmental and societal impacts.
- Tradeoffs: Safety, capacity, cost, Environment, societal
- Earthwork calculations using average end area method and trapezoidal methods
- Context-sensitive design

Processes

- Roadway alignment design process: Designing a road that meets design standards
- Selection of design parameters
- Horizontal alignment design
- Calculate the minimum length of simple horizontal curves on the basis of maximum allowable vehicle forces
- Che ck for sight distance obstructions along inside of horizontal curve
- Will spiral (transitional) curves be used?
- Determine tangent runout and superelevation runoff lengths
- Check for adequate tangent length provided between curves
- Vertical curve design
- Determine maximum and minimum allowable tangent grades
- Calculate the minimum and maximum length of vertical curves
- Calculate the length of sag vertical curves on the basis of headlight stopping sight distance, comfort, drainage, and appearance
- Determine roadside design elements on the basis of design parameters
- Geometric design decision process: Designing a road that meets the needs of all users and considers the context, cost, and impacts of the road
- Perform roadway alignment design process
- Calculate earthwork calculations and determine other major quantities for initial cost estimate
- Look at the roadway design from the perspective of all road users (pedestrians, bicycles, transit) to determine if changes to the design are necessary
- Review the roadway design in terms of context-sensitive solutions to determine if roadway meets the needs of the community and the environment

Tools

- Geometric design guides and standards
- All other tools
- *A Policy on Geometric Design of Highways and Streets* ("Green Book")
- *Roadside Design Guide*
- *Guide for the Planning, Design, and Operation of Pedestrian Facilities*
- *Guide for the Development of Bicycle Facilities*
- *Flexibility in Highway Design*
- Computer design tools
- AutoCAD and Civil 3D
- Microstation and GeoPak/InRoads

Context

- Urban roadway design
- Rural roadway design
- Seeing geometric design from adherence to standards
- Seeing geometric design from a larger context

FIGURE 6 Geometric design knowledge table.

Concepts	Processes	Tools	Context
Where does the money come from? Public finance Capital costs Operations & Maintenance Costs Gas Tax/Highway Trust Fund Vehicle-miles-traveled (VMT) tax Private finance Toll road investments Public/private partnerships Private investment Capital costs Operation & maintenance costs Responsibilities of the federal government Responsibilities of state governments Responsibilities of local governments	Collection of gas taxes Input to the Highway Trust Fund Highway Trust Fund bailouts (General Fund) Distribution to the states Implementation Capital investment Maintenance investments Research	Cost-benefit analysis Cost-effectiveness analysis	Highway Trust Fund VMT tax Gas tax

FIGURE 7 Transportation finance knowledge table.

Concepts	Processes	Tools	Context
Transportation supply and demand, and their relationship Travel supply Personal cost of travel Social costs of travel (congestion, pollution, etc.) Externalities: positive and negative, and importance of pricing for externalities (this could go under processes) Best solution (price so price equals marginal cost) Second-best solution (provide subsidies to competing modes) Travel demand Induced demand (temporal, spatial, modal convergence) Impact of policy on supply and demand, with examples Parking policies Congestion pricing Road widening, etc. TDM in general	Application of how travel demand and supply are determined (refer to planning and land development tables) and evaluated Evaluation methods for externalities: market valuation (when goods are exchanged in the market) and contingent valuation (using methods such as willingness to pay, etc.)	Cost-benefit analysis Cost-effectiveness analysis Economic analysis Revealed-preference and stated-preference surveys	London congestion charging scheme HOT lanes Examples of induced demand: “Cannot build out of congestion” FTA criteria for new starts

FIGURE 8 Transportation economics knowledge table.

Concepts	Processes	Tools	Context
Scientific methods/ hypothesis test Problem identification, hypothesis, methodology, hypothesis testing, conclusions and recommendations Typical crash categories: Head-on, rear-end, sideswipe Basic safety analysis Crash frequency versus crash rate How crash data is characterized Standard data sets and types	Scientific method (explore use) Problem identification Hypothesis Methodology Hypothesis testing Conclusions and recommendations Highway safety improvement programs	Crash data as well as other data sources (Fatality Analysis Reporting System or local data set where available)	Seeing traffic safety in the larger picture of traffic operations and planning

FIGURE 9 Traffic safety knowledge table.

Concepts	Processes	Tools	Context
Public transportation: Familiarity with system design, modes, and associated operating characteristics Modes: Bus, light rail, heavy rail, commuter rail, and paratransit System design: Radial vs. linear systems, collector-distributor systems Capacity and level-of-service analysis Integration within larger transportation system: connectivity, access & mobility, transit-oriented design Nonmotorized modes: Familiarity with bicycle and pedestrian facility development and operations	Plan multimodal transportation systems Determine transit vehicle and route capacities Determine transit headways and frequencies on the basis of estimated demand Seasonal and daily use patterns Identify safety conflicts for non-auto users Incorporate transit and nonmotorized right-of-way considerations into street design	*Transit Capacity and Quality of Service Manual*	Planning phase: Use of analyses to design preliminary routes for transit service, bicycle, and pedestrian facilities or to determine facilities in need of improvement Design phase: Determination of basic operating characteristics of transit (headways, frequencies) and nonmotorized facilities Operations phase

FIGURE 10 Transit and nonmotorized transport knowledge table.

Working group members have presented earlier stages of the effort through the presentation of papers at the Transportation Research Board Annual Meeting in January 2010, the American Society of Engineering Educators in June 2010, and at several regional ITE district meetings (*7, 8*). The members will make presentations on their future efforts and continue the outreach effort to broader audiences.

In 2010 through 2011, two pilot studies will be conducted. The working group's results will be used in introductory transportation classes at the University of Wyoming, Laramie, during the fall semester and at Lafayette College, Easton, Pennsylvania, during the spring semester. Both pilot studies involve the redesign of the introductory transportation engineering course from the ground up and around the knowledge tables and learning outcomes. An assessment and evaluation plan for the pilot studies is under development.

Another key step that will be part of the working group's efforts is to provide more guidance to instructors on core content versus optional content. The intent of the working group is not to dictate what exactly should be taught in a particular course. The group therefore created more course content than could fit into a typical semester-long course so that instructors would have flexibility in their content selection. Some of the content should be viewed as more critical to the transportation profession than other material, and the working group will prioritize some of it. The efforts of the pilot studies over the next year will be important for determining the amount of time it is likely to take to cover the information in the various knowledge tables.

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