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The publication of the "fourth" full edition of the *Highway Capacity Manual* (HCM) in the fall of 2000 represented a major step forward in state-of-the-art highway capacity and quality-of-service analyses. Even as this major step is taken, however, old issues reemerge and new ones arise as to the core concepts involved, the directions that such analyses should take in the future, and the needs of HCM users. Now that HCM has begun to address system and multimodal measures, the nature and meaning of capacity and level-of-service concepts need to be reexamined. The role of simulation must be more clearly defined, as must the limitations of more conventional highway capacity analyses. As databases improve, the question of statistical accuracy and stochastic variations in standard measures may seem more important, even though the inherent variability in traffic flow characteristics remains essentially unchanged. The need for software to implement ever more complex methodologies raises additional issues. As the Committee on Highway Capacity and Quality of Service and its members consider these and other important issues, an attempt to outline the major issues and alternatives that should be examined is made. In addition, some suggestions as to potential paths to follow are provided.

In the early 1990s, as the publication of the 1994 *Highway Capacity Manual* (HCM) approached, the chair of the Committee on Highway Capacity and Quality of Service (HCQS), Adolf D. May, Jr., mused that the name of the committee's primary document ought to be reconsidered. The word "highway" ought to be replaced by the word "transportation," he said because the manual's new emphasis on pedestrians, bicycles, and transit gave it much more than just a highway focus. Similarly, the word "capacity" ought to be replaced with "capacity and quality of service," as operational and level-of-service (LOS) analyses were clearly its primary applications. Finally, May suggested that the word "manual" be replaced with the word "guidelines" because it has never been intended for the HCM to set official standards. For a brief moment in time, the committee considered the possibility that its namesake product did not have a name. After considering a variety of alternatives, the historic title was retained, and the committee turned its attention to development and production issues.

The "fourth" edition of HCM was released in December 2000 (*1*), and it is still titled the *Highway Capacity Manual.* The 2000 edition, however, represents a significant departure from previous editions in format, content, and terms of the user community for which it is intended. The 2000 HCM reflects today's technology in its use of audio, visual, and electronic means to enhance the delivery of information to professionals with widely ranging backgrounds and interests. Technically, it opens the door to new areas that will be the subject of further development in the years to come. As planning applications are given special emphasis, questions about the relationship of such applications to traditional operational analyses are raised. As the issues of corridor and system analyses are qualitatively addressed, new questions such as appropriate measures of effectiveness, types of models, and the meaning of such analyses come to the fore. Although the new manual recognizes the existence and importance of simulation models, the need to define the boundary between such models and the more traditional approaches of the HCM is heightened. The need for software to implement the increasingly complex models of the HCM raises the question of verifying the "correctness" of software products in implementing those models. The increased sophistication of the analysis procedures contained in HCM raises the question of whether the additional effort and specialized expertise required are appropriate for a user community that has grown substantially in both size and breadth of professional interest since publication of the first HCM 50 years ago (*2*).

The 2000 HCM moves away from the purely facility-oriented focus of previous editions and toward a more systemwide perspective. Part IV of the 2000 HCM presents methods for aggregation of the results of point analyses into facility, corridor, and areawide assessments. Nevertheless, this expanded focus is not completely reflected in the current structure of the HCQS, which is primarily organized into facility-specific subcommittees and groups, although some recent subcommittees and task forces are addressing broader issues.

Thus, in many ways the 2000 HCM marks a critical decision point in the history of highway capacity and quality-of-service analyses. The 2000 HCM greatly improves the state of the art, but it also introduces significant questions, which must be resolved before work toward a "fifth" edition begins in earnest.

This paper attempts to define and discuss some of the more important issues facing the HCQS as it maps out its plans for the next several years. The issues discussed herein are not meant to provide an exhaustive review; rather, some thoughts on the more obvious conceptual matters are presented as a basis for discussion.

THE "FIFTH" EDITION: HCM 20??

One of the most immediate issues facing the HCQS is when to target the publication of the next full edition of HCM and how to handle interim partial updates.

HCM has an interesting publication history (*3*). The first manual was published in 1950 (*2*) and provided basic design guidelines for some types of facilities. HRB *Bulletin 167: Highway Capacity Studies* (*4*) was published in 1957, constituted a virtual updating of the first edition, and is often referred to as edition 1½. The second

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full edition was published in 1965 (*5*) and introduced the LOS concept for the first time. It also included much expanded material on freeways. In 1980, *Transportation Research Circular 212: Interim Materials on Highway Capacity* (*6*) provided an advance look at some of the procedures under development for the third full edition, which was published in 1985 (*7*). Three interim updates to the third edition were released. In 1992, a new chapter on multilane highways was released. In 1994, "Edition 3½" included updated versions of about half the material in the manual (*8*). In 1997, "Edition 3¾" included further updates, particularly with regard to signalized and unsignalized intersections (*9*).

The four full editions of the manual were published in 1950, 1965, 1985, and 2000. Although the 15- to 20-year time period between publication of each full edition seems like a long time, it is important to note that work on the 2000 HCM actually began nearly 10 years earlier with the publication of *Transportation Research Circular 371: A Program of Research in Highway Capacity* (*10*) in 1991. The committee believed that it was important to get the results of new research into the hands of the user community as quickly as possible. This belief led to the increased frequency of interim releases, which in turn led to the publication of substantial new material in 1994 and 1997. The release of such frequent interim updates raised some critical issues:

- Could the user community absorb significant changes on what had become a 3-year cycle?
- Considering the extensive production time requirements associated with the new multimedia format of the 2000 HCM, would it even be possible to publish and distribute multimedia updates on a 3-year cycle?
- Given the lag between software development and the release of a new edition of the manual, would the necessary computational tools even be in place within the 3-year window of use?

The last issue became the most critical. Given that several of the methodologies, particularly signalized intersection analysis, required software for implementation, the procedures of the 1997 edition in many cases were not really put into use until late 1998 or 1999, when the software became available. In fact, the 1997 HCM introduced a new appendix to the chapter on signalized intersections that defined a new iterative model for estimation of average signal timing for an actuated signal on the basis of detector and controller parameters. However, none of the major software developers has yet included a module that implements the procedure described in this appendix. Thus, it has rarely been used in the field, given the great difficulty of implementing the procedure manually—made more difficult by the fact that the appendix does not completely describe the model in terms that could lead to the development of software. In truth, many agencies have never officially moved to the 1997 manual, resulting in inconsistent applications of the latest methodologies.

The 1997 HCM experience seems to suggest that 3 years is too soon to release major changes in methodology. On the other hand, the 15- to 20-year time period between new editions is also unacceptable. Driver characteristics and technology can change significantly over such periods, making it necessary to update and revise many of the underlying behavioral assumptions and the predictive models that depend on them.

A better approach might be to target full editions for every 10 years. Interim updates at 5 years might be permitted, but they would be restricted to relatively minor tinkering that could be easily incorporated into software products.

In any event, the committee must balance the ability of the user community to absorb major changes with the desire to have the most up-to-date materials in use at all times.

WHAT IS "CAPACITY"?

The concept of capacity is defined in a way that invites consideration of stochastic variation. Yet in its application, such variation is largely ignored even in the 2000 HCM. The 2000 HCM continues to define capacity in terms of "reasonable expectancy"; that is, it indicates that capacity represents a maximum flow rate that can be expected to be achieved repetitively at a single location and at all locations with similar roadway, traffic, and control conditions. This definition allows capacity to vary at a given location over time and at similar locations in different places. Ample data have been collected over the years to support this concept. Because traffic flow characteristics are clearly stochastic in nature, it follows that, even for a given time period, the capacity of a movement or an approach is also likely to be a stochastic phenomenon.

Yet when models are calibrated, no clear defining statistic is used as representative of capacity. Several obvious questions come to mind:

- If the maximum flow rate varies at a given location over time or even within a single time period, what statistic defines the official value: the 15th percentile, the median, or the 85th percentile?
- What is the standard deviation of maximum flow rate observations at a given location? Should capacity be defined on the basis of a lower confidence boundary?
- If a standard percentile is established and multiple similar locations still yield various results, what percentile measure should be used?

The concept of "reasonable expectancy" suggests that a lower percentile value be used to define capacity. Use of a 15th percentile, for example, would establish that at a given location the predicted value could be achieved 85 percent of the time. A similar criterion for multiple locations might also be applied. Whether capacity should ever be stated as $x \pm 1.96E$ (where E is the standard error of the mean) with 95 percent confidence is a more subtle issue that could involve legal issues, given the variety of uses that some HCM procedures experience.

However, even if the issue of stochastic variation is addressed, there are other conceptual issues to be addressed. For basic freeway sections and multilane highway sections, capacity is still defined as the maximum rate of flow that can be sustained without breakdown. A remaining fundamental issue is the relationship of such a capacity value compared with the queue discharge rates that exist after a breakdown. Field observations of the difference between the two values have not been consistent. Arguments have been made that it is the queue discharge value that should be considered "capacity." For signalized intersections, the concept that the saturation flow rate may vary with the length of a green phase is recognized in the *Canadian Capacity Guide* (*11*); current procedures do not take such variations into account.

Thus, even for a concept as simple as capacity, there are significant issues to be addressed. Given the improvements in data collection technology and the ability to collect and analyze larger, more systematic databases, it is critical that each concept be very carefully defined in more specific terms with its measurement firmly in mind.

LOS ISSUES

The LOS concept was introduced in the 1965 HCM, replacing the 1950 HCM concepts of basic, possible, and practical capacity. It defined LOS in the following terms:

> Level of service is a qualitative measure of the effect of a number of factors, which include speed and travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating costs. (*5*, p. 7).

In the 1997 and 2000 editions, the definition of the concept is similar, with two major exceptions: references to safety and operating costs have been eliminated.

In theory, LOSs have always been defined in terms of the operational parameters that drivers and passengers experienced as they traversed a defined roadway section. An analysis of LOS definitions in the 1965 HCM, however, revealed that actual defining boundaries were based on volume levels [or volume/capacity (V/C) ratios] (*12*). Volume (or flow) has never been included in the definition of the concept and, as a point measure, is not directly experienced by drivers or passengers. The 1985 and subsequent editions have attempted more faithful implementations of the concept. Safety and operating costs were dropped from the definition in the absence of any historic or current attempts to include specific criteria related to these items.

In the 1965 HCM, and even in the 1985 HCM, LOSs provided another function: they allowed descriptive definitions for several types of facilities for which no measures of effectiveness had been defined or for which no predictive models were available. By 1994, however, predictive methodologies producing estimates of specific measures of effectiveness were included for all facility types in the HCM.

Although the concept of LOS has now been strongly ingrained into the lexicon of professionals and transportation decision makers, HCQS has periodically reexamined the concept for its utility in the current context. Several key issues emerge.

User Perceptions

Although LOS is intended to be a quality measure describing the user's operational experience on a facility section, HCM methodologies have not been based on extensive user surveys. Although some attempts have been made to study this link, "perceptions" remain difficult to measure and interpret, given that most studies rely on hypothetical or simulated situations. The problem of discerning how drivers and passengers truly react to real-time traffic situations remains to be solved.

It might be inferred from media-based opinion polls and anecdotal experience that users at least recall the total experience of a given trip. The daily commute to work could be viewed as good or bad on the basis of the total travel time and traffic conditions. Drivers would not often be inclined to judge the quality of specific portions of the trip, such as the experience at a single intersection or at a single ramp-merge on the freeway. Yet that is what LOS attempts to do. A driver might experience the entire range of defined LOSs on the trip to work; the driver's subjective rating of the trip's quality, however, would more likely relate to the totality of the experience.

As corridor and system LOS measures begin to be considered, the issue gets even more complex. A multimodal corridor might have a defined overall LOS, but the user would experience mode-specific conditions along a particular route. Thus, as larger conglomerations of facilities and modes are considered for LOS analysis, the concept of user perceptions is left even further in the dust.

How Is LOS Used?

LOSs are used in a variety of ways, many of which were not intended by the HCQS. Design standards are often stated in terms of LOS objectives, although these are not set or considered by the HCQS. In recent years, LOSs are often incorporated into development regulations, with mitigation fees correlated to the predicted impact of the generated traffic on existing LOSs. When specific LOS boundaries are set, they are based on the collective judgment of members of the HCQS (and its subcommittees), not on user perception surveys.

The inclusion of LOS criteria in development legislation is particularly vexing. When LOS definitions and criteria are changed (as they are in each subsequent HCM), HCQS is effectively changing legislation, a role that is completely unintended and quite troubling.

Multiple Measures of Effectiveness

Predictive methodologies now exist for many types of facilities that can produce multiple measures of effectiveness, each of which has an effect on the quality of service experienced by the user. Thus, it is possible to predict both speed and density (in addition to capacity) for most uninterrupted flow facilities. At signalized and unsignalized intersections, average and maximum queue lengths can be estimated, in addition to delay and capacity. Yet with the exception of the two-lane rural highway analysis procedure, the 2000 HCM uses only a single measure of effectiveness to define the LOS for any particular facility type.

As the profession becomes more sensitive to the importance of the total driving experience in defining overall service quality, the likelihood is that the number of measures of effectiveness that should be appropriately considered will increase. It is possible that different measures will be of primary interest in different situations, such as undersaturated and oversaturated conditions. Blind adherence to single-measure LOS criteria retards intelligent consideration of the various available quality measures as a whole and arbitrarily limits the ability to respond to the informational needs of the owners-operators and users of the transportation system.

Procedural Quirks in LOSs

In their current form, LOSs create step-function quality descriptors that are more or less arbitrarily superimposed on continuous relationships. Because of this, some small changes can appear to be significant, whereas some very significant changes can appear to be trivial. For example (using the 2000 HCM criteria), a signalized intersection might be improved to reduce control delay from 56 to 54 s/vehicle. The LOS is improved from E to D by a relatively small improvement. Another intersection might be improved to reduce delay from 79 to 59 s, a much larger improvement. Nevertheless, the LOS is unchanged (LOS E), as the range for LOS E is from 55 to 80 s. Although the LOS step function was desirable when only gross or qualitative estimates of delay were available, it can serve to mislead when the models on which it is based establish continuous relationships.

Another quirk of LOS criteria is that they do not reflect local driver and passenger perceptions. What is "acceptable" in New York City is probably not "acceptable" in a small rural community. Since the magic letters A through F carry general connotations with them, they cannot reflect such differences in local perceptions of service quality.

Finally, there is the peculiar relationship between LOS F to a V/C ratio of 1.00. In the uninterrupted flow methodologies, LOS F occurs (by definition) whenever the V/C ratio (demand to capacity) exceeds 1.00. The fact that V/C ratios of 1.00 occur on such facilities at relatively consistent densities is convenient but hardly necessary to the procedure. For signalized and unsignalized intersections, however, LOS F merely indicates unacceptable levels of delay. This can occur at V/C ratios of less than or greater than 1.00. More confusing, however, are cases in which V/C ratios are >1.00 but the delay (based on a short analysis period of 15 min) is less than that required for LOS F. This conundrum is a direct result of the LOS concept definition, which arbitrarily excludes flow rates (or V/C ratios) from among the indicators of service quality. For interrupted flow points, there is no quality parameter that correlates directly and solely to V/C ratios, and a consistent relationship cannot, therefore, be defined. The result, however, is often misinterpretation of analysis results. Given acceptable LOS predictions, V/C ratios can easily be ignored, even when they suggest that a "failure" has occurred. Alternatively, many users have come to rely on LOS as an indicator of facility sufficiency when it is not necessarily so.

From the authors' point of view, these points strongly argue for abandonment of LOS in future editions of the HCM. The manual can and should give users multiple measures of effectiveness that can be used to judge the quality of operations. The V/C ratio should also be presented as a measure of capacity sufficiency and should be given weight equal to those of other operational measures. The manual can also provide guidance on the interpretation of various measures, but it should stop short of defining what is "good" and what is "bad." It is not necessary to define arbitrary ranges in continuous relationships when all traffic professionals should understand the meaning of such measures as speed, density, delay, and queue length. The numbers speak for themselves and are adequate descriptors of any traffic situation.

Abandonment of the arbitrary labeling of conditions as LOSs A to F allows local jurisdictions to set their own targets for acceptability. It opens up opportunities to be more descriptive and informative in characterizing oversaturated conditions. It also forces legislatures to define what they mean in numerical terms when they forge development laws and regulations. Finally, it gets the HCQS out of the lengthy discussions necessary to forge consensus on where specific LOS boundaries should be and allows its members to focus on identifying appropriate measures of effectiveness and then improving on the ability to predict those measures.

It must be noted, however, that many professionals continue to support LOSs as a critical means of communicating complex relationships to the public and to decision makers, who are generally not engineers or planners.

PRECISION, SENSITIVITY, AND ACCURACY

Over time, the improvement of HCM algorithms and models has led to increasing complexity, greater sensitivity to a wider range of input variables, and models that can be used to provide very "precise" answers, that is, to measures of effectiveness evaluated to the nearest digit, tenth of a unit, or even hundredth of a unit.

What is more difficult to answer, however, is how much the basic accuracies of these algorithms and models have been improved. First, the concept of model accuracy should be characterized by the following question: given the input parameters available to the typical user, how will the predicted output measure of effectiveness compare to field-measured values of the same parameter? In truth, for most HCM methodologies, the answer to this question is, "we don't know." The reasons that the answer is not known are myriad:

- In many cases, field data were insufficient to statistically calibrate relationships and simple graphic fits were used.
- Most methodologies involve a series of interconnected algorithms. Although statistical data are available for some of the pieces, virtually no methodology has statistically assessed basic accuracy on the basis defined herein.
- Some methodologies combine data-based regression models with theoretical models for which no database exists.
- In some recent cases, validations of pieces of methodologies consist of a comparison of model results with simulation results.

In addition, in the few cases in which some statistical measures are available, the results are hardly awe inspiring. To take one example from the 1994 HCM, the equation for density in the ramp-influence area of a single-lane ramp merge had an R^2 value of 0.88 and a standard error of estimate of 1.65 passenger cars (pc)/km/lane (2.68 pc/mi/lane). This is one of the better fits for an HCM model for which such statistics are available. Interpreting this, a density of 17.3 pc/km/lane (28 pc/mi/lane) means that there is 95 percent certainty that the result is in the range of 17.3 ± 1.96 (1.65) pc/km/lane [28 ± 1.96 (2.68) pc/mi/lane] or is between 14.68 and 20.53 pc/km/lane (22.75 and 33.25 pc/mi/lane). This range is sufficient to cover the defined LOSs from B through E. Furthermore, the predicted value uses an input from another model that predicts the proportion of approaching freeway flow remaining in lanes 1 and 2 (for which no statistics are published in the HCM).

The original research for the signalized intersection methodology in 1983 (*13*) showed substantial standard errors for delay prediction. More recent research into unsignalized intersections (NCHRP Project 3-46) has again found delay to be a highly variable parameter, even under relatively constant roadway and traffic conditions. In the case of signalized intersections, model constructs were developed in the original research. Those models were modified before inclusion in the 1985 HCM and were further modified in 1994 and 1997 without any analysis of their accuracy. They also depend on predictions of V/C ratios that derive from a string of many models, some of which are regression based and others of which are theoretical. The point is that there is very little knowledge of the ultimate accuracies of most HCM methodologies, from input variables to the predicted measures of effectiveness. This is compounded by the fact that many of the defined measures of effectiveness are difficult to measure in the field (such as delay and density).

Two major policy points are critical in response to this situation:

- The HCQS should take a break from developing new methodologies or refining the precision of existing ones and embark on a mission to more carefully validate the methods of the 2000 HCM. NCHRP, TCRP, and FHWA should be enlisted to support this effort because it is easily as important as research into new models and methodologies.
- The issue of complexity must be reconsidered in light of the results of such validation efforts.

Complexity has been an ongoing issue for many years. As research has progressed, methodologies have tended to take into account more input variables and have modeled basic mechanisms in more sophisticated and complex ways. The ready availability of computer packages has provided support for the use of models that can no longer be implemented by hand computation or on simple worksheets. Although the result enables a wider range of underlying conditions to be evaluated and provides greater sensitivity to those underlying conditions, it creates a veritable "black box" for more and more users as time goes on.

Such complexity and sensitivity may be unwarranted if results of validation demonstrate substantial statistical uncertainty in the resulting predictions of measures of effectiveness. On the basis of what little is already known about the statistical accuracy of methodologies, it is the opinion of the authors that systematic validation will only document considerable statistical uncertainty.

Consider also that all capacity and quality-of-service analyses begin with a demand volume, either measured or predicted. The literature adequately documents that measured flows are subject to substantial stochastic variation. Future demand prediction is even more uncertain.

Demonstration of greater accuracy is necessary but not sufficient to justify the use of more sophisticated and complex analysis procedures. It must also be shown that these new tools contribute to better investment and design decision making by transportation professionals if they are to have lasting value. If the degree of increased accuracy is insufficient to affect final investment and design choices or if the transportation professionals using these procedures are not adequately trained to appropriately apply and interpret the results, a simpler and slightly less accurate procedure may be equally or even more effective.

The ability of computational technology enables the use and applications of more complex models and relationships. On the other hand, the ability to create ever more complex models does not automatically mean that they should be created. A concerted validation effort is necessary to answer the question of whether they should be. Complexity that leads to improved engineering decisions is clearly justified; complexity that does not should be avoided at all costs.

EXTENSION OF ANALYSIS TO CORRIDORS AND SYSTEMS

HCQS was established in 1944 at a time when there was a clear and pressing need to develop uniform methods for estimating the hourly capacity that could be achieved by various types of highway facilities. The United States was about to undertake the development of a national highway system, and so the key transportation investment decisions of the time centered on questions regarding the appropriate sizes of these facilities. Thus, the focus of the procedures developed by the then-new HCQS was almost entirely on ensuring the sufficiency of the individual facility.

Today, it is clear that the transportation system is more than the sum of its individual parts. Long ago, the transportation profession concluded that a singular supply-side perspective would not suffice and determined that investment decisions would need to be based on more than just the projected V/C ratio of any particular facility. As the profession began to embrace the notion that moving people and goods is more important than moving vehicles, it also began to adopt a multimodal approach to investment decision making. It did so, however, without any clear idea of how to prioritize the many different investment options that suddenly became available. As a result, these decisions are now being made on an ad-hoc basis according to guidelines and rules adopted at a local or a regional level instead of at a national level. Every transportation improvement project is now seen to cause a cascade of ancillary impacts on the remainder of the transportation system. Adding a right-turn lane at a signalized intersection, for example, simultaneously increases the capacity of the intersection, reduces the travel time on a bus route (a bus route that uses the intersection), and increases the delay to vehicles turning from a minor street at a downstream intersection. Similarly, the many parts of the transportation system combine in myriad ways to mold a user's perspective of overall service quality.

Consider, for example, a hypothetical commuter going to work on a typical weekday. The commuter begins by leaving home on the local street that runs by her house and then turns onto a two-lane highway. The two-lane highway becomes a multilane highway as it enters the city limits, and the commuter enters a six-lane freeway to get to a convenient park-and-ride facility on the outskirts of town. The commuter then boards a bus to downtown and completes the trip by walking from the bus stop to the office. This sample commuter used many different components of the transportation system on a single commute, all of which must function as an integrated whole if the system is to provide optimal service and efficiency. How should the "capacity" of this system be defined? What quality of service was provided by the transportation system in this case? What key performance measures should be used to collectively describe the current state of the system? How does the single-trip experience of the commuter relate to the typical experiences of all other travelers? What transportation investment would create the greatest positive impact on these performance measures?

Within the next 10 years, a window of opportunity exists for the HCQS to assist transportation decision makers in identifying means for the effective evaluation of the impact on system performance characteristics of not only new right-turn lanes but also intelligent transportation system deployment strategies, transit service improvement programs, new pedestrian facilities, and even access management plans. To do this, however, the authors believe that the HCQS will need to step away from the currently limiting LOS concept in lieu of a broader view of system performance. Indeed, the HCQS is only one key player in addressing such questions that must ultimately involve many TRB committees and other groups of professionals, decision makers, and users.

SIMULATION AND HIGHWAY CAPACITY ANALYSIS

Even among professionals, there are many different views of what simulation is. Simulation models can be event based or time based, stochastic or deterministic, microscopic or macroscopic, and so forth. What is clear, however, is that as the HCQS begins to grapple with a systemwide evaluation, simulation becomes an ever more important tool to consider.

The real issue for the committee is whether simulation consists of models that compete with the HCM or whether (and how) simulation tools can be systematically integrated to answer important capacity and quality-of-service questions.

CORSIM, for example, provides many system measures not currently available as outputs from traditional the HCM analytic models. Questions of consistency of definitions and measures and issues of accuracy, however, have prevented the direct endorsement of its use to address system issues. Nevertheless, transportation professionals continue to use CORSIM and other simulators to answer questions that are not addressed by the HCM.

Simulation is a permanent and valuable part of the analytic environment, and it is doubtful that comprehensive system issues can be addressed without its use. Over the next decade, HCQS must determine whether it can integrate simulation tools into the HCM (and, if so, how). The alternative is to define boundary conditions in which simulation is a more effective and efficient approach to problem solving than the traditional approaches of the HCM.

This is a most difficult choice. On the one hand, any limited group or committee must have some boundaries on the subjects of its attention and responsibility. On the other, integration of all available modeling tools to the solution of capacity and quality-of-service issues offers greater opportunities for success.

SOFTWARE DILEMMA

As methodologies become more complex, the need for computational software for effective implementation increases. With the 2000 HCM, analysis of freeway systems, two-lane highways, signalized and unsignalized intersections, and arterials now virtually requires the use of computational software.

The HCQS has grappled with this problem over a number of years. Although Highway Capacity Software is the leading software tool now on the market, it is not now, nor has it ever been, formally reviewed, endorsed, or tested by the HCQS. There will be a number of implementing software products released in support of the 2000 HCM, and none of these will be formally reviewed or endorsed by the HCQS either. The HCQS has, until now, taken the position that it is not in the business of testing or formally validating whether any software correctly implements the procedures of the HCM.

The problem, however, gets worse. When procedures cannot be implemented by hand, even the development of sample problems requires computational aids. The committee has discussed, for example, the idea of creating a "bank" of many sample problems that would be made available to software developers. In theory, they could test their products against the results for these problems. Whose responsibility is it, however, to verify the validity of the computational tools needed to develop the sample problems?

At this point many of the models and methodologies of the HCM would best be developed in computerized form. Paper descriptions would more logically follow, not precede, the computer algorithms.

What, then, should the HCQS do? If verification of software products is left entirely to software developers, the committee loses any effective control over the implementation of its product (HCM). In terms of usage, it can be said (and has been said) that "the software is the manual."

The following positions are suggested:

- The HCQS (and its subcommittees) should assume responsibility for verifying the computational engines for each of its methodologies. No special effort should be undertaken to make these computational engines user friendly or to include within them "bells and whistles," graphic outputs, and so forth. They should simply generate numerical answers to the full range of input scenarios for which the methodology exists.
- Approved computational engines could then be used to generate the desired "bank" of sample problems.
- The sample problem bank—and, indeed, the code for computational engines—would be made available to any software developer that requests it.

This, of course, places an additional burden on the HCQS and its members; and it is likely that support from NCHRP, TCRP, or FHWA would be needed to complete such an effort.

Verification would have to involve multiple experts completing computations by hand (it is always possible, even if it is quite inconvenient, to do so) and multiple experts examining the details of computational engines and their output. This would not be a perfect solution, but it would improve on the need to rely entirely on software manufacturers for the validation of their own products.

If the additional complexity of procedures is warranted by more accurate results, then so is the additional effort required to validate the improved procedure. The HCQS made the statement in 1994 that it would no longer sacrifice accuracy for simplicity. In making such a statement, however, it seems appropriate that the responsibility for ensuring computational correctness should also be undertaken, at least to the extent practicable.

SUMMARY AND CONCLUSIONS

With the publication of the 2000 HCM, there is a critical window of opportunity for the HCQS and other transportation professionals and decision makers to take the time to consider some of the critical philosophical issues in capacity and quality-of-service analyses before moving forward to the next major edition of the HCM. It is the authors' hope that this opportunity is fully explored.

From its earliest days, the HCQS has performed one of the most important functions in the transportation profession, and its publication, the HCM, has been a principal guide in transportation decision making, planning, and design. The HCM continues to be a high-quality mix of observed transportation behavior and physical and theoretical models. Where extant data and models are not available, the HCQS and its members impose their collective professional judgment to "patch" procedures as needed. The widespread use of the HCM is a testimony to the quality of the ongoing commitment and expertise of the members of the HCQS and its subcommittees. In the coming years, the challenge to the HCQS will be to address an ever-increasing breadth of problems to an ever-increasing audience of users. The task is indeed daunting. If any group, however, is capable of tackling it, it is the HCQS and its participants.

The opinions and views expressed herein are, of course, those of the authors. Thus, the recommendations that follow are not the only possible courses of action. Rather, they are but one set of inputs into what will be a most interesting and stimulating discussion that takes place over the next several years.

To summarize,

1. It is recommended that the HCQS consider that full editions of HCM be issued at 10-year intervals, with 5-year interim updates limited to relatively simple adjustments that can be easily implemented in software.
2. The definition of capacity should be sharpened to include statistical criteria that reflect the stochastic nature of capacity. Some existing conceptual issues should be resolved before the publication of the next full edition.
3. The historic mechanism of step-function LOSs should be abandoned in the next full edition of the HCM in favor of multiple measures of effectiveness and numerical values from continuous relationships. The judgments implicit in LOS-specific definitions should be left to decision makers and transportation professionals.
4. Before embarking on the development of new or updated procedures for a "fifth" edition, it is recommended that the HCQS undertake a more rigorous validation of the accuracy of existing procedures. Support from FHWA, NCHRP, and TCRP should be sought for this effort.

5. The accuracy versus simplicity issue should be seriously revisited in light of the results of validation studies. Complexity that does not improve transportation decision making should be avoided.

6. Corridor and system analysis approaches and the use of simulation remain important issues to address before progressing on to a “fifth” edition of the HCM. Important conceptual issues should be resolved before proceeding.

7. The HCQS should undertake an effort to formally validate basic computational engines for all of its procedures in an effort to produce more reliable and consistent highway capacity software products and to maintain control over the implementation of HCM methodologies.

It is the authors’ hope that these discussions provide helpful input concerning the important issues in highway capacity and quality-of-service analyses of transportation facilities and systems.

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