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Optimization-based assisted calibration of traffic simulation models

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ABSTRACT

Use of traffic simulation has increased in recent decades; and this high-fidelity modelling, along with moving vehicle animation, has allowed transportation decisions to be made with better confidence. During this time, traffic engineers have been encouraged to embrace the process of calibration, in which steps are taken to reconcile simulated and field-observed performance. According to international surveys, experts, and conventional wisdom, existing (non-automated) methods of calibration have been difficult or inadequate. There has been extensive research on improved calibration methods, but many of these efforts have not produced the flexibility and practicality required by real-world engineers. With this in mind, a patent-pending (US 61/859,819) architecture for software-assisted calibration was developed to maximize practicality, flexibility, and ease-of-use. This architecture is called SASCO (i.e. Sensitivity Analysis, Self-Calibration, and Optimization). The original optimization method within SASCO was based on "directed brute force" (DBF) searching; performing exhaustive evaluation of alternatives in a discrete, user-defined search space. Simultaneous Perturbation Stochastic Approximation (SPSA) has also gained favor as an efficient method for optimizing computationally expensive, "black-box" traffic simulations, and was also implemented within SASCO. This paper uses synthetic and real-world case studies to assess the qualities of DBF and SPSA, so they can be applied in the right situations. SPSA was found to be the fastest method, which is important when calibrating numerous inputs, but DBF was more reliable. Additionally DBF was better than SPSA for sensitivity analysis, and for calibrating complex inputs. Regardless of which optimization method is selected, the SASCO architecture appears to offer a new and practice-ready level of calibration efficiency.

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1. Introduction

Computer programs for traffic simulation have become more advanced in recent decades. Use of traffic simulation has increased significantly; and this high-fidelity modeling, along with moving vehicle animation, has allowed important transportation decisions to be made with better confidence. During this time, traffic engineers have typically been encouraged to embrace the process of calibration, in which steps are taken to reconcile simulated and field-observed traffic performance. One example of such encouragement can be found in the U.S. Federal Highway Administration (FHWA) guidelines for applying micro-simulation modeling software (Traffic Analysis Toolbox, 2004). These guidelines state "the importance of calibration cannot be overemphasized"; and refer to a study (Bloomberg et al., 2003) by Bloomberg et al., which makes the following statement: "Recent tests of six different software programs found that calibration differences of 13% in the predicted freeway speeds for existing conditions increased to differences of 69% in the forecasted freeway speeds for future conditions." Therefore, these studies and guidelines demonstrate some of the dangers of neglecting calibration.

Despite the importance of calibration, practical application has been difficult. According to international surveys, top experts, and conventional wisdom, existing (non-automated) methods of calibration have been difficult and/or inadequate. Consulting engineers and DOT personnel have expressed strong interest in making calibration faster, cheaper, easier, and requiring less expertise. Comprehensive surveys (Brackstone et al., 2012) revealed that 19% of simulation users do not perform any amount of calibration, and that only 55% of calibration efforts are based on guidelines that exist in the literature (Traffic Analysis Toolbox, 2004, 2007; Vaughn and McGregor, 2007). Finally, some simulation users believe that they have somewhat mastered the process of calibration; but that many years of experience are required to master this process, or that high-quality calibration is overly time-consuming.

There has been significant research to improve calibration for traffic simulation. Some of this research focuses on traffic assignment and origin–destination flows. A second area of research focuses on pattern matching of simulated versus field-measured vehicle trajectories and/or speed-flow relationships. A third area of research focuses on simulation-based optimization, in which the numeric discrepancy between simulated and field-measured results becomes an objective function to be minimized. Many of these research projects and papers have not provided the level of flexibility and practicality that are typically required by real-world engineers. In the papers by Lee and Ozbay (2009), Lee et al. (2013), and Menneni et al. (2008), the authors present substantial literature reviews for both manual and automated calibration techniques. The authors then emphasize that, despite the extensive efforts, existing calibration procedures continue to require excessive time and expertise.

With this in mind, a patent-pending (US 61/859,819) architecture for software-assisted calibration was developed, within the simulation-based optimization (SO) family of methods. The new architecture uses a database of input parameters, to predefine a narrow set of trial values to be used during optimization. The architecture also allows engineers to prioritize input and output parameters, and specify a tolerable computer run time, prior to initiating the SO-based calibration process. The "directed brute force" (DBF) search process is believed to be a key element in making the architecture flexible and practical, for real-world use. These same features were later extended to provide an enhanced platform for sensitivity analysis, and optimization. The acronym term "SASCO" (Sensitivity Analysis, Self-Calibration, and Optimization) was adopted. Thus, SASCO provides a database-centric framework to support any one of these three analysis types.

In recent years, Simultaneous Perturbation Stochastic Approximation (SPSA) has gained favor as an efficient method for optimizing computationally expensive, "black-box" traffic simulations. For example in 2007, Balakrishna et al. (2007) selected SPSA "for its proven performance and computational properties in large-scale problems". In 2007–2008, Ma et al. (2007) and Lee's dissertation (Lee and Ozbay, 2008) calibrated PARAMICS traffic simulations with SPSA. Also in 2008, the Transportation Research Board posted a research needs statement (TRB Research Needs Statements) for simulation model calibration, saying "recent research indicates that the SPSA algorithm can solve very large noisy problems in a computationally attractive fashion." More recently in 2013–2014, Paz et al. (2014) successfully demonstrated CORSIM calibrations with SPSA, while Lu et al. (2015) proposed an enhanced SPSA algorithm for traffic assignment. Therefore SPSA appears promising for assisted calibration of computationally expensive simulations, and a possible alternative to the DBF optimization originally implemented within SASCO.

As such, this paper will assess the qualities of DBF and SPSA, so they can be applied in the right situations. The scope is limited to calibration (without validation) of average output values (not distributions); with data collection from one real-world corridor, using one underlying simulator (FRESIM, which is part of CORSIM). Follow-up studies will hopefully perform similar assessments with more optimization methods, validation following calibration, calibration of output distributions, on more real-world corridors, using more simulators.

2. SASCO architecture

The SASCO architecture was developed to enhance sensitivity analysis, self-calibration, and optimization capabilities of any complex model (e.g. CORSIM, VISSIM, AIMSUN). As stated earlier, SASCO belongs to the simulation-based optimization (SO) (Law and McGomas, 2000) family of methods. Numerous input combinations are evaluated toward minimizing or maximizing an objective function. When the goal of SO is calibrating a simulation model, minimizing the difference between simulated and field-measured outputs is sometimes the objective function. Another important aspect of SO is the searching

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